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TENNESSEE VALLEY AUTHORITY

HYDROMETEOROLOGICAL REPORT NO. 56

Probable Maximum and TVA Precipitation Estimates With Areal Distribution for Tennessee River Drainages Less Than 3,000 Mi^2 in Area

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PROBABLE MAXIMUM AND TVA PRECIPITATION ESTIMATES WITH AREAL DISTRIBUTION FOR TENNESSEE RIVER DRAINAGES LESS THAN 3,000 MI^2 IN AREA

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ABSTRACT This study provides probable maximum precipitation (PMP) and TVA precipitation estimates for durations of 6 to 72 hr and areas of 1 to 3,000 mi^2 for basins located in the Tennessee River Watershed. The first part gives procedures for estimating PMP and TVA precipitation for small basins ($\leq$100 mi^2) for durations of 6 to 24 hr, while the second part gives procedures for estimating PMP and TVA precipitation for large basins (100 mi^2-3,000 mi^2) for durations of 6 to 72 hr. Specific PMP and TVA precipitation estimates are presented for 26 basins in the Tennessee River Watershed.

Procedures are also presented to compute the areal distribution of PMP and TVA precipitation. This includes the areal distribution in concurrent drainages to the main subbasin.

Finally, precipitation amounts antecedent to the maximum 24-hr and 3-day storm (both PMP and TVA precipitation) are derived.

1. INTRODUCTION

1.1 Purpose

The purpose of this report is to provide updated estimates of probable maximum precipitation (PMP) and Tennessee Valley Authority (TVA) precipitation for area sizes up to 3,000 mi^2 for the Tennessee Valley region. Additional information on antecedent rainfall criteria is also provided. As such, this report supersedes Hydrometeorological Report (HMR) No. 45 (Schwarz and Helfert 1969), [hereafter, all reports in this series will be referred to as HMR No.]. This report brings together into one document all revisions, modifications and changes, such as the Addendum (Schwarz 1973). In addition, the report has been expanded to include procedures for estimating precipitation over concurrent drainages.

1.2 Background

Generalized estimates of 1- to 72-hr PMP and TVA precipitation for basins ranging between 5 and 3,000 mi^2 in the Tennessee Valley watershed were provided in HMR No. 45. However, recent hydrometeorological studies for other locations have indicated that some of the concepts used in the development of HMR No. 45

*Former staff member of Water Management Information Division can be further extended. In addition, our knowledge of the interaction of terrain with storm dynamics for short durations and small areas has improved.

The initial study separated procedures used to develop PMP estimates for areas equal to or less than 100 mi^2 and greater than 100 mi^2. The procedures were based upon the predominant storm type producing extreme precipitation amounts for these ranges of area sizes. This separation resulted in significantly different PMP estimates for basins that differed by only a few square miles in area. A review of this problem in 1973 revealed that the differences resulted from an inadequate consideration of the effects of convective activity for areas just somewhat larger than 100 mi^2. An Addendum (Schwarz 1973) provided procedures to resolve this problem.

A discussion of the concept of PMP and some of the practical problems of estimating PMP are discussed in HMR No. 41 (Schwarz 1965). A more detailed discussion may be found in Weather Bureau Technical Memorandum HYDRO-5 (Myers 1967). More recent studies, such as HMR No. 51, "Probable Maximum Precipitation Estimates, United States East of the 105th Meridian," (Schreiner and Riedel 1978), HMR No. 52, "Application of Probable Maximum Precipitation Estimates - United States East of the 105th Meridian" (Hansen et al. 1982), and HMR No. 55, "Probable Maximum Precipitation Estimates, United States Between the Continental Divide and the 103rd Meridian" (Miller et al. 1984a), provide evolutionary ideas that have influenced the development of this report. In addition, procedures to compute areal distributions of PMP and TVA precipitation in mountainous areas where orographic effects are important have been included in this report.

Any need for PMP estimates for basins larger than 3,000 mi^2 must be met by individual basin studies (e.g., Schwarz 1961, Schwarz 1965) or by a future generalized study.

1.3 Authorization

The authorization for this study are agreements between the Tennessee Valley Authority and the National Weather Service in 1966, 1982, 1983 and 1984.

1.4 Concept of PMP and TVA Precipitation

The definition of PMP used in the present report is the same as that used in HMR No. 52, namely, "Theoretically the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographical location at a certain time of the year." This definition represents a slight change from that used in HMR No. 45, and results in a need to follow procedures outlined in HMR No. 52, and described in chapter 4 of this report, to convert storm PMP to basin-averaged PMP.

The large analyzed sample of extreme storms experienced in the United States has provided a few storms assumed to have produced precipitation from water vapor in the atmosphere with near optimum efficiency. In such cases, nature can be looked upon as performing all the necessary integrating of rain-producing factors except for some slight upward adjustment for moisture charge. Such rare storms are transposed to adjoining regions. In the present report, the general level of the small basins PMP is controlled by a few such storms, e.g., --the

Smethport, PA storm of July 17-18, 1942--which dumped over 30 in. of rain in less than 6 hr just to the northeast of Smethport, PA.

The general level of nonorographic PMP for the larger basins is based upon the moisture maximization and envelopment of major storms of record that are transposable to some portion of the Tennessee River basin. Among the more important storms are those centered near Altapass, NC in July 1916, Boyden, IA in September 1926, Warner, OK in May 1943, Tyro, VA in August 1969 and Zerbe, PA in June 1972.

Like the PMP, the TVA precipitation concept from HMR No. 41 is preserved in the present report. Basically, the TVA precipitation is defined as the level of precipitation resulting from transposition and adjustment (without maximization) of outstanding storms, which have occurred elsewhere in the Tennessee Valley. A few of the most extreme events are undercut. In this report, in order to make the TVA precipitation estimates agree with actual storm experience, the variable depth-duration concept given in HMR No. 45 is continued here, which, for example, recognizes that at the TVA level of precipitation, there is little chance that the maximum 72-hr storm event also includes the maximum 6-hr rainfall event.

1.5 Organization of Report

Chapter 2 describes the development of 24-hr PMP and TVA precipitation for basins up to 100 mi^2. Generalized procedures for estimating precipitation up to 72 hr for basins between 100 mi^2 and 3,000 mi^2 are the subject of chapter 3. Chapter 4 discusses areal distribution of PMP and TVA precipitation for all area sizes considered in this report. In chapter 5, stepwise procedures for computing PMP and TVA precipitation and the areal distribution are presented together with examples. PMP and TVA precipitation estimates for 26 basins in the Tennessee River watershed are given in chapter 6. Finally, chapter 7 describes the development of antecedent precipitation criteria.

Throughout this report there are a number of figures that are considered "working diagrams," i.e., they are important for use in making computations of PMP and TVA precipitation according to the procedures outlined in chapter 5. Since the information on these selected figures is critical to the accuracy with which the answer can be determined, a set of oversized figures (approx. 1:825,000) have been prepared. Anyone having an interest in these oversized diagrams should contact the Tennessee Valley Authority.*

1.6 Broadscale Topographic Features of the Tennessee Watershed

The Tennessee River watershed can be divided into essentially four topographic subregions: Western Basin, Cumberland Plateau, Valley and Ridge, and Blue Ridge, shown in figure 1. The Western Basin includes the Mississippi Alluvial Plain, Highland Rim and the Nashville Basin (fig. 1). The Western basin is relatively low, with rolling hills and is generally referred to as the Western region in this report. The Cumberland Plateau is not a flat plateau, but characterized by irregular highlands and ridges which are particularly steep along the edge. The Valley and Ridge subregion is comprised of parallel ridges running from southwest to northeast. The Cumberland Plateau and the Valley and Ridge subregions combine

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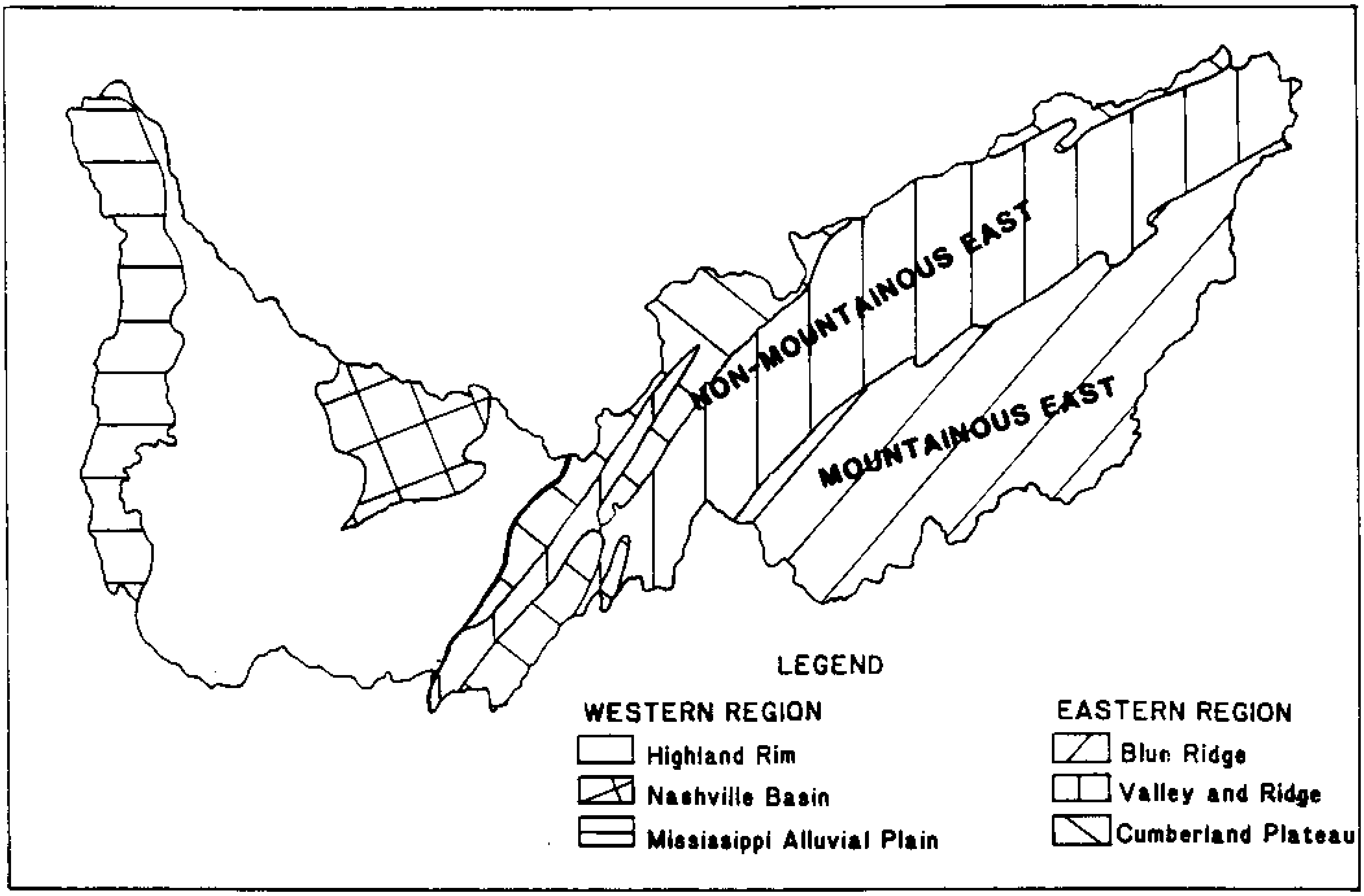


Figure 1.--Generalized physiographic provinces of the Tennessee River watershed.

to represent the non-mountainous east in this report. The Blue Ridge subregion, which forms the mountainous east in this report, is bounded by: (1) the mountains which form the eastern and southern boundary of the Tennessee Valley watershed and (2) the Unakas and Great Smoky Mountains, which run from the southwest through the northeast along the northwestern boundary of the region and reach elevations exceeding 6,000 ft.

With regard to broadscale controls on storm rainfall, the mountains in the Blue Ridge subregion in figure 1 provide localized sheltering to the interior of the mountainous east and the Valley and Ridge region from significant moisture inflow from the south and east. The Cumberland Plateau shelters the Valley and Ridge and western slopes of the southern Blue Ridge from storms moving from the west. The Western Basin is relatively free from any broadscale sheltering.

In this report, the Western Basin will generally be referred to as the western TVA region, while the other three provinces (Cumberland Plateau, Valley and Ridge, and Blue Ridge) represent the eastern TVA region. The Blue Ridge province will be referred to as the mountainous east to more clearly distinguish this region regarding orographic considerations.

1.7 Application of This Report

This report represents the current understanding of the Hydrometeorological Branch, NWS for the level of PMP and TVA precipitation and antecedent conditions in the Tennessee Valley for drainages $\leq$ 3,000 mi^2. Included in these estimates is a procedure for determining the areal distribution used to derive drainage-average values, as well as a procedure for modification of this distribution in orographic regions, and consideration of precipitation occurring over concurrent drainages. As such, these results represent the latest concepts in PMP determination for this region.

It is our recommendation that the procedures presented here be applied according to the respective regions within the Tennessee Valley, and take preference to PMP estimates determined from any other existing PMP study (vis., HMR No. 41, 45, 51 and 52) that covers this region. Numerous checks were made in nonorographic regions between estimates from this study and those from HMR No. 51 and 52. Differences were small and can be expected between results from a limited region and one that provides results for a large region.

In the eastern TVA region shown in figure 1 (coincident with the stippled designation in HMR No. 51), the methods presented in this report are pioneering efforts to consider orographic effects on a generalized scale in the Appalachian Mountains. These methods draw on procedures developed in NWS HYDRO 39 (Miller et al. 1984b), NWS HYDRO 41 (Fenn 1985), and HMR No. 55 (Miller et al. 1984a).

2. SUMMER PMP AND TVA PRECIPITATION FOR SMALL BASINS (<100 mi^2)

2.1 Development of PMP Storm Type

2.1.1 Introduction

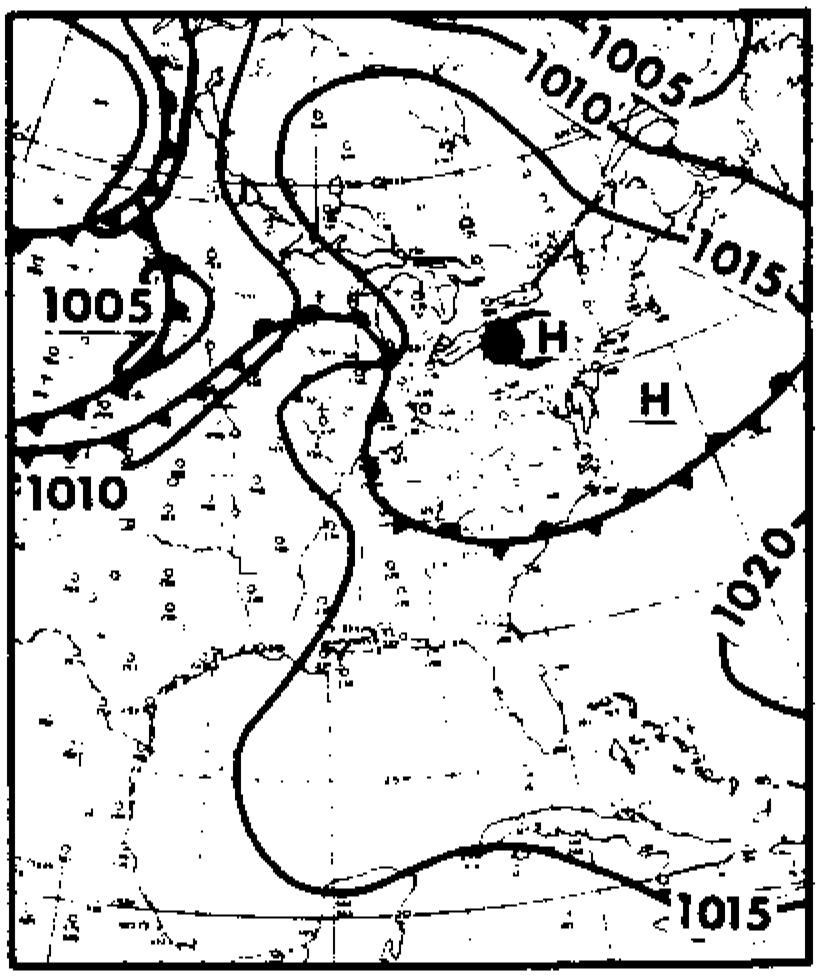
A first step in determining PMP for the Tennessee basin is to establish the type of storm which will produce the rains of PMP magnitude over the basin. The PMP storm for small areas is thunderstorm related, but the storm type differs in important ways from a "typical" thunderstorm situation.

The typical summer thunderstorm generally lasts less than 1 hr--not so with the PMP-type storm which may extend beyond 6 hr. The typical summer thunderstorm is quite restricted in area. In the PMP-type thunderstorm, larger areas may be involved with more thunderstorm activity. The typical summer thunderstorm occurs in the afternoon or evening in the Tennessee River Valley. The PMP-type thunderstorm often occurs during the nighttime hours, but can occur at any time.

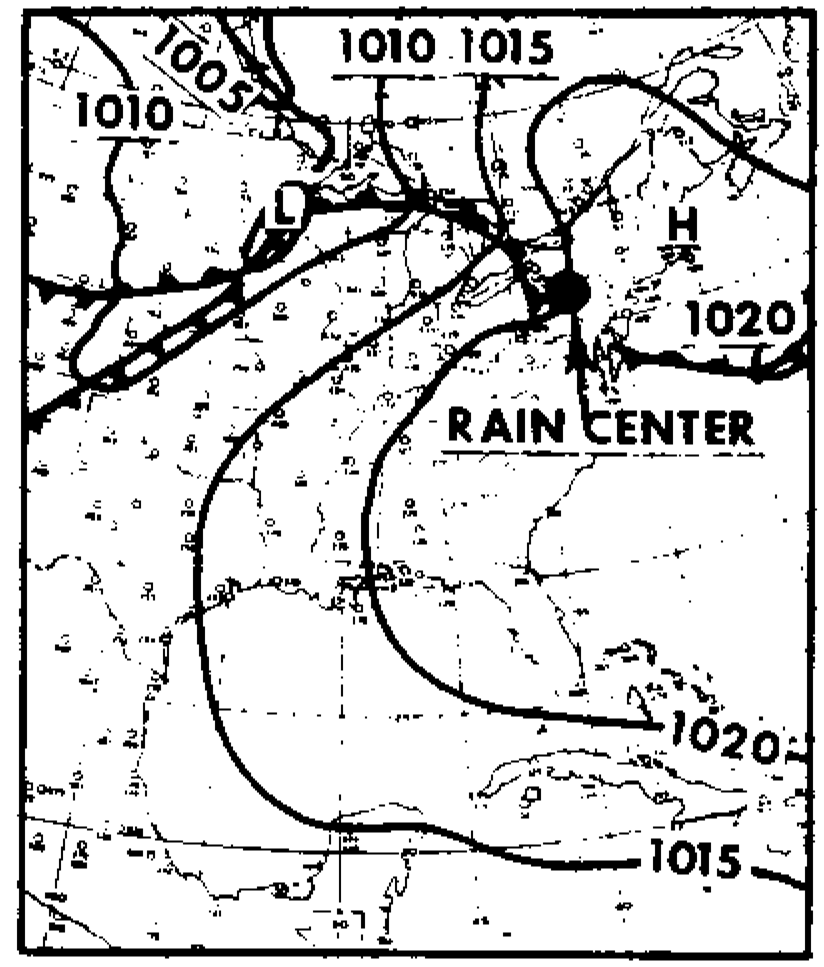
Only a very few storms have yet been observed anywhere in the United States that clearly resemble the PMP type. The best example resembling the PMP storm type for small areas that could occur over the Tennessee River basin is the Smethport, PA storm of July 17-18, 1942. Surface weather maps for this storm are shown in figure 2. Characteristics of this outstanding storm are important to establishing the PMP storm type for the Tennessee River watershed. Additional insight into the probable characteristics of the PMP storm comes from examination of other intense short-duration storms and some major large-area long-duration storms, and from the climatology of thunderstorms, including their diurnal and other characteristics.

2.1.2 Intense Rains in and Near the Tennessee River Watershed

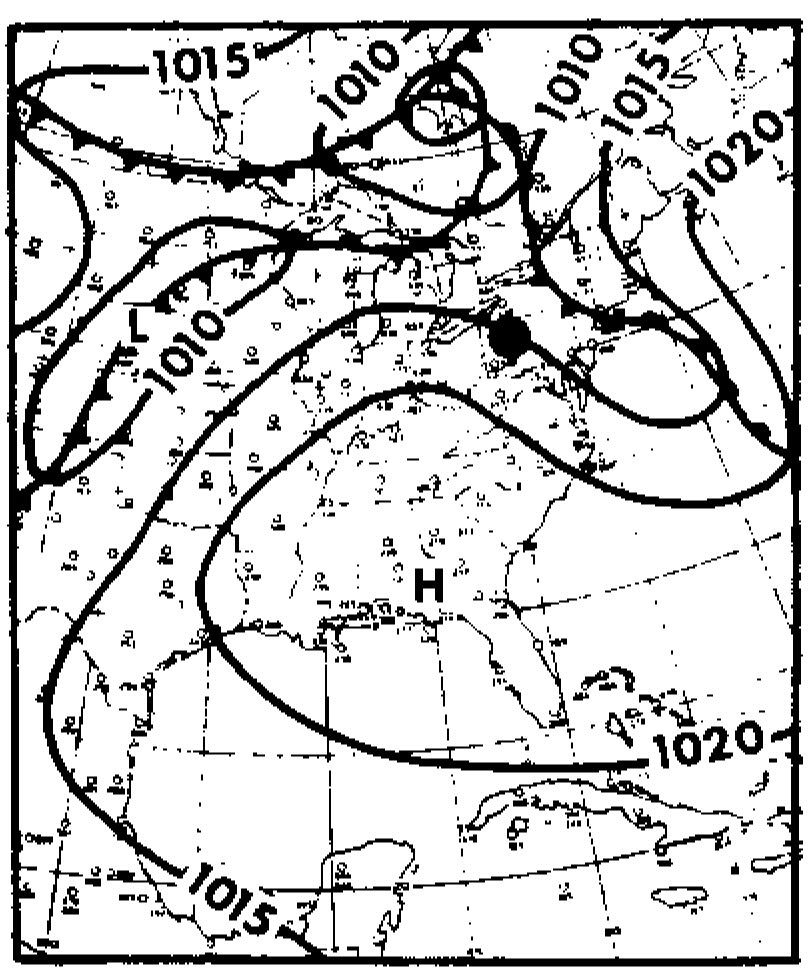
The dates, location and other information regarding intense rains in or near the Tennessee River watershed are shown in table 1. The basic information on these storms was provided by the TVA (1924-1982). Regularly reporting rainfall stations rarely catch such outstanding rains. The TVA has long recognized that the average spacing of rain gages fails to sample most extreme summer storms.



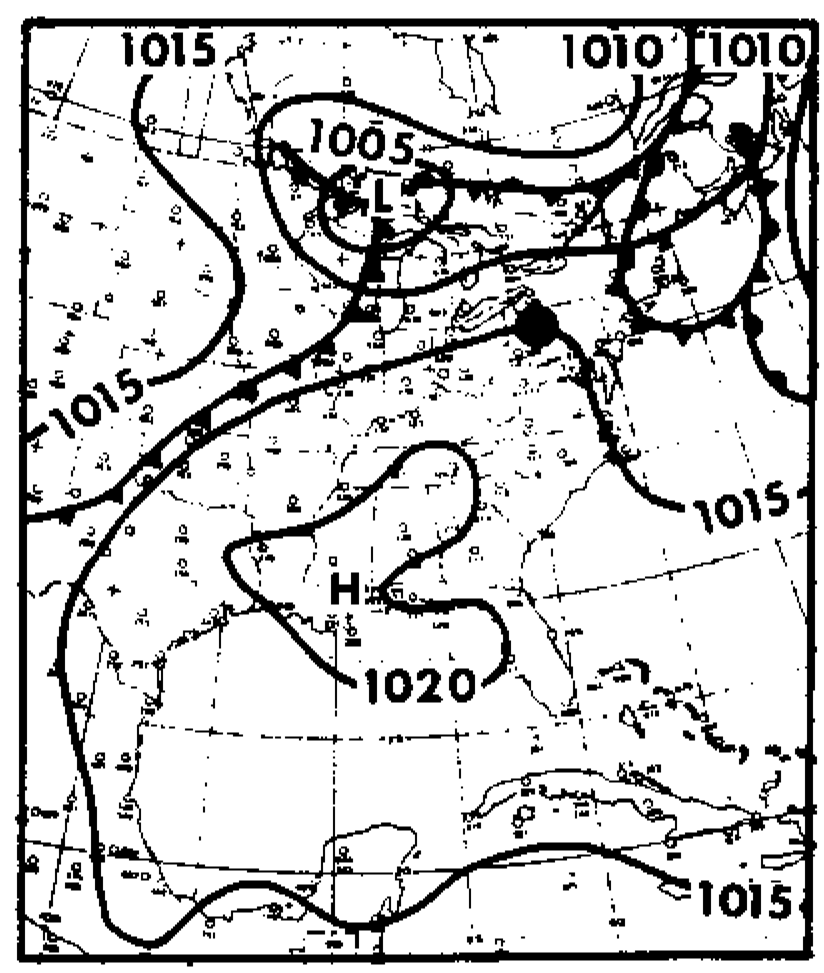
July 16, 1942 Sea Level 1230GMT



July 17, 1942 Sea Level 1230GMT



July 18, 1942 Sea Level 1230GMT



July 19, 1942 Sea Level 1230GMT

Figure 2.—Surface weather maps for the July 16–19, 1942 storm at Smethport, PA.

Table 1. Intense rainfalls from small area storms in or near the Tennessee River watershed

Date	Approximate Lat. (N)	Locations* Long (W)	Index No.	Durations (hr.)	Area (sq. mi.)	Depth (in.)
June 13, 1924	36°18'	82°16'	0	3.5	Point	14.4
June 2, 1937	36°16'	85°46'	1	0.3-0.4	0.35	5.5
June 3, 1937	35°49'	82°30'	2	1.5	4	6.2
June 3, 1937	36°02'	83°56'	2	0.5	4	1.8
July 30, 1937	36°15'	83°05'	3	2	4.3	5
May 22, 1938	35°57'	85°02'	4	2	Point	11
June 18, 1938	35°27'	86°48'	5	3	30	9
July 7, 1938	35°05'	82°50'	6	1	4	6
July 8, 1938	35°14'	86°06'	7	0.75	Point	8.3
August 4, 1938	35°46'	83°26'	7a	3-4	Point	12.3
June 9, 1939	37°12'	80°48'	8	4	25	10
April 20, 1940	35°47'	88°22'	9	1	6	1.73
June 7, 1940	35°14	88°24'	10	1	0.125	3.5
June 18, 1940	36°27'	84°05'	11	0.75	7	4.5
July 8, 1940	36°22'	83°03'	12	1	1.5	4.5
July 11, 1941	35°11'	86°47'	13	2	15	6
July 13, 1941	36°10'	82°24'	14	2	7.45	4
August 6, 1943	35°05'	85°04'	15	0.75	Point	3
May 15, 1946	35°08'	85°17'	16	1.5	Point	6
May 15, 1946	35°08'	85°17'	17	3	6.21	6.7
June 28, 1947	36°04'	82°50'	18	3.5	Point	5.4
July 28, 1947	35°45'	83°15'	19	3	Point	5.8
June 4, 1949	35°55'	85°28'	20	2	Point	9.5
July 16, 1949	36°14'	83°20'	21	1.75	Point	4.5
July 19, 1949	35°22'	83°13'	22	1	0.98	5.5
July 25, 1951	35°06'	84°39'	23	2	8	5.6
July 28, 1951	35°38'	83°00'	24	0.75	Point	6.0
July 28, 1951	36°04'	82°50'	25	0.5	Point	3.2
Sept. 1, 1951	35°33'	83°10'	26	1	Point	6.5
Sept. 1, 1951	35°43'	83°31'	27	1	Point	6.5±
June 5, 1952	34°58'	83°55'	28	1	2	4.2
June 13, 1952	35°41'	85°48'	29	3	Point	10.5
June 13, 1952	35°09'	84°11'	30	6	Point	7.8
July 6, 1953	36°54'	81°19'	31	2	5	4
July 18, 1953	35°02'	85°12'	32	2	Point	5.2
June 13, 1954	36°36'	82°11'	33	0.92	50.2	3.0
Aug. 8-9, 1954	35°07'	85°36'	34	3±	30±	10±
March 21, 1955	35°06'	87°26'	35	0.2	Point	0.8
June 21, 1956	37°06'	83°43'	36	3	Point	11.7
Sept. 6, 1957	35°46'	82°25'	37	2	3.56	5.5

Table 1. Intense rainfalls from small area storms in or near the Tennessee River watershed (continued)

Date	Approximate Lat. (N)	Locations* Long (W)	Index No.	Durations (hr.)	Area (sq. mi.)	Depth (in.)
June 30, 1956	35°36'	83°01'	38	1	Point	10-12
Nov. 18-19,1957	35°42'	81°55'	39	2.0	Point	10.3
July 23, 1958	35°52'	84°31'	40	0.6	Point	2.0
July 24, 1958	35°51'	84°41'	41	2.5	Point	2.8
August 12, 1958	35°48'	82°40'	42	1.5	Point	3.2
June 9, 1959	35°38'	88°11'	43	1	10.6	2.1
Aug. 25, 1959	35°02'	85°12'	44	1	Point	2.4
June 16, 1960	35°32'	87°01'	45	3	Point	12.8
July 26, 1960	34°33'	84°04'	46	3	Point	12.5
August 10, 1960	35°51'	84°41'	47	1.5	11.7	3.4
August 10, 1960	35°56'	84°19'	48	3.3	Point	9
June 12, 1961	36°02'	82°06'	49	2.5	3.49	8.5
July 23, 1963	34°27'	86°56'	50	1.5	4	7
April 28, 1964	35°11'	84°49'	51	1	1	4
July 24, 1965	36°36'	83°43'	52	4	Point	11
July 24, 1965	36°14'	84°17'	53	3	10	12
April 26, 1966	35°10'	88°12'	54	1.33	2	5.2
August 9, 1966	35°13'	88°19'	55	1.5	Point	5.2
December 8, 1966	35°20'	86°55'	56	5	2	3.3
May 12, 1967	35°40'	87°10'	57	1	Point	3.3
June 3, 1967	35°12'	82°15'	58	6	Point	5.5
August 4, 1968	36°16'	82°10'	59	0.50	Point	2.2
Sept. 16, 1968	34°35'	87°50'	60	5	Point	11.1
April 25, 1970	35°51'	84°40'	61	1.5	Point	3.0
June 15, 1970	35°32'	88°15'	62	0.75	Point	1.8
August 3, 1971	36°58'	81°55'	63	1	Point	1.8
August 5, 1971	36°40'	81°45'	64	0.58	Point	1.9
August 2, 1972	36°35'	82°30'	65	1	Point	3.5
April 26, 1973	35°02'	85°10'	66	2	Point	5.5
May 18, 1974	36°50'	81°45'	67	0.75	Point	3.2
May 30, 1974	35°40'	83°45'	68	5	Point	6.6
June 22, 1974	36°22'	82°03'	69	1.5	Point	2.2
October 1, 1977	36°38'	82°30'	70	4	Point	3.3
Sept. 10, 1978	36°35'	83°10'	71	0.75	Point	4.0
May 3, 1979	35°40'	88°38'	72	4	Point	4.6
June 22, 1979	36°22'	82°03'	73	3	Point	2.6
July 21, 1979	34°55'	86°42'	74	2	Point	4.3
August 29, 1981	34°30'	86°12'	75	1	Point	6.3
July 30-31, 1982	36°00'	83°58'	76	4	Point	8.2
August 17, 1982	35°20'	85°17'	77	3	Point	15.5

Its engineers have made many field investigations immediately following the occurrence of severe storms to obtain "bucket" rainfall measurements (TVA 1961), and there is a fairly complete record of such storms from this region dating back to 1924 (table 1).

The meteorology of the intense storms of table 1 was investigated by studying the surface, and where available, upper-air weather charts. The weather maps of these storms showed no consistent pattern of synoptic conditions in relation to causes of the heavy rains. About half of the storms involved surface fronts separating contrasting air masses. Some showed strong low-level inflow of moisture (e.g., May 15, 1946 and July 19, 1949), while others had weak moisture inflow (e.g., June 4, 1949).

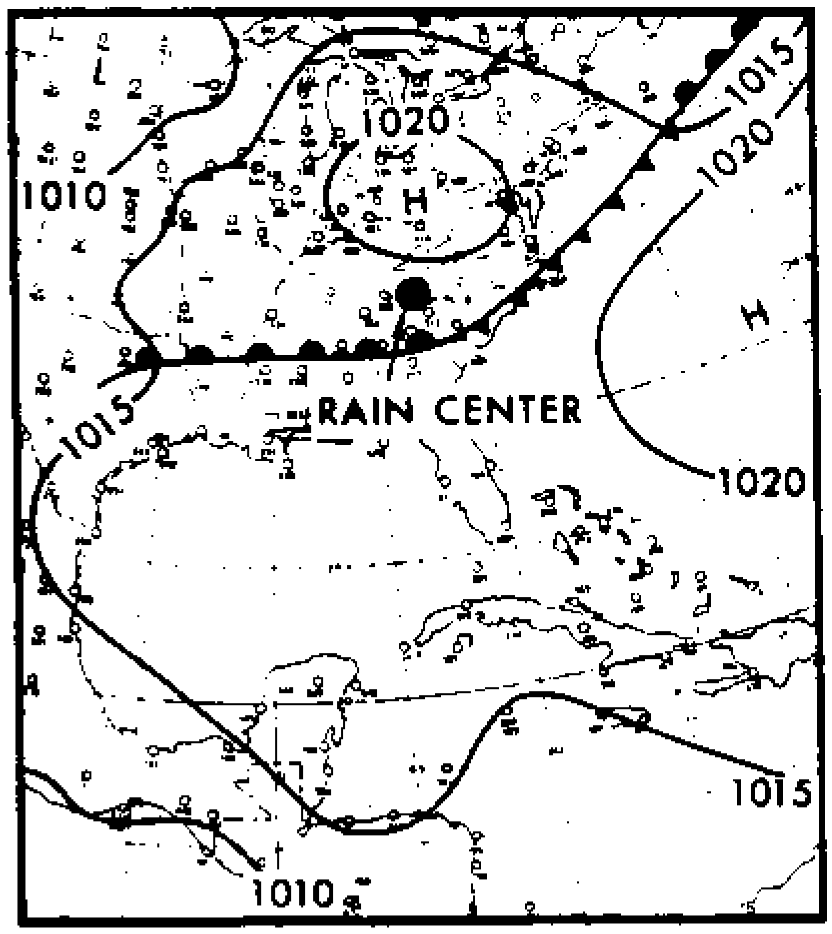
Figures 3 and 4 show weather maps for two of the more important TVA storms. The June 30, 1956 storm (fig. 3) reportedly produced 10 to 12 in. of rain (table 1) in about 1 hr, based on runoff computations. The precipitation fell mostly between noon and 1 p.m. on June 30. A weak warm front at the surface and a minor trough of low pressure at 500 mb seem to have been contributing factors. A similar intense storm involving more surface inflow was that of June 21, 1956, near Manchester, KY (fig. 4). This storm also produced nearly 12 in. of rain in 3 hr (table 1).

Regardless of the weather factors operating, a common feature of most extreme rains in and near the Tennessee River watershed, as with similar rains elsewhere, is the degree of organization and geographic "fixing" of convective activity. Huff and Changnon (1961) reported such a feature in an investigation of severe rainstorms in Illinois. Huff (1967) discussed two additional Illinois storms, emphasizing the importance of a succession of convective cells reaching their greatest intensity over the same general area. These Illinois storms, in lasting about 4 hr, come a little closer to representing the PMP storm type for a maximum 24-hr rain in the Tennessee Valley than did most of the TVA storms which had shorter durations. Maddox (1981) also discussed the effects of convective activity on a mesoscale storm over the central Mississippi Valley. Both authors hypothesized that the strong changes in temperature, wind, and pressure-surface heights in and around such storms were the result of a deep layer of mid-tropospheric convective warming.

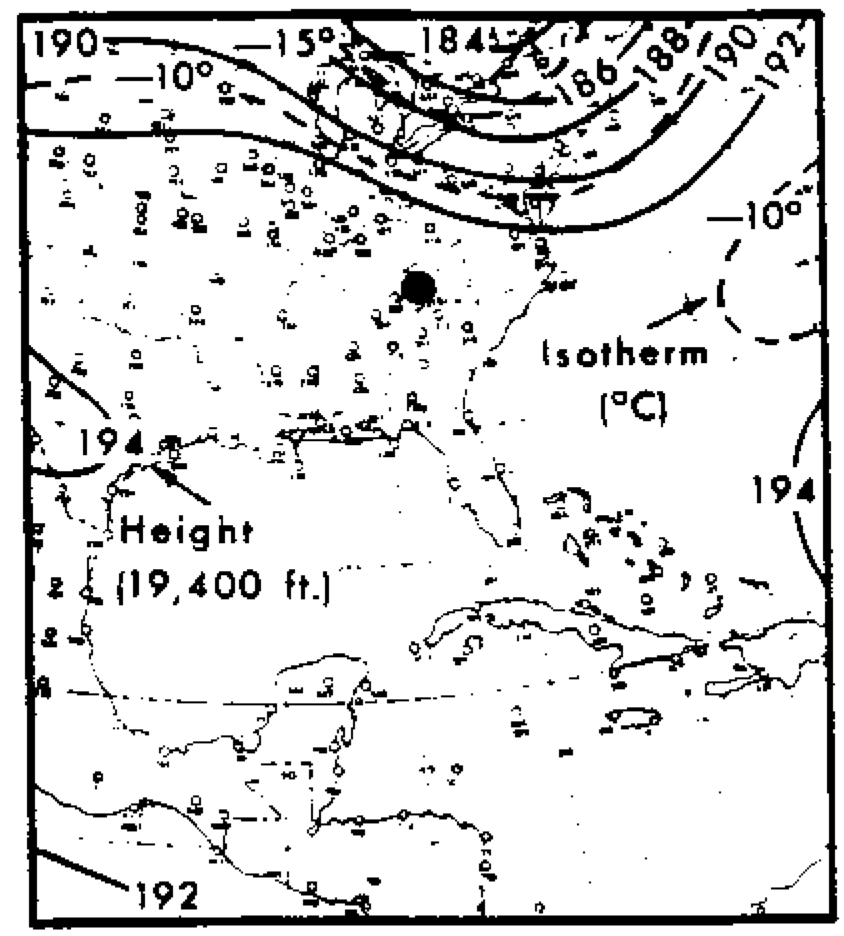
One does not always find fronts or other easily identifiable causes of intense rains whether in the Tennessee River watershed or elsewhere. A discussion (Woodley 1967) of a wintertime occurrence of such organized convection within a warm-air mass concluded that "...convective organization is the difference between little rain in one region and 10 in. in another." Only slight triggering mechanisms are necessary to release the air's convective instability. Such triggering disturbances, when they exist aloft, are not always detectable in synoptic scale upper-air analyses because of the sparse upper-air network.

2.1.3 Orographic Considerations

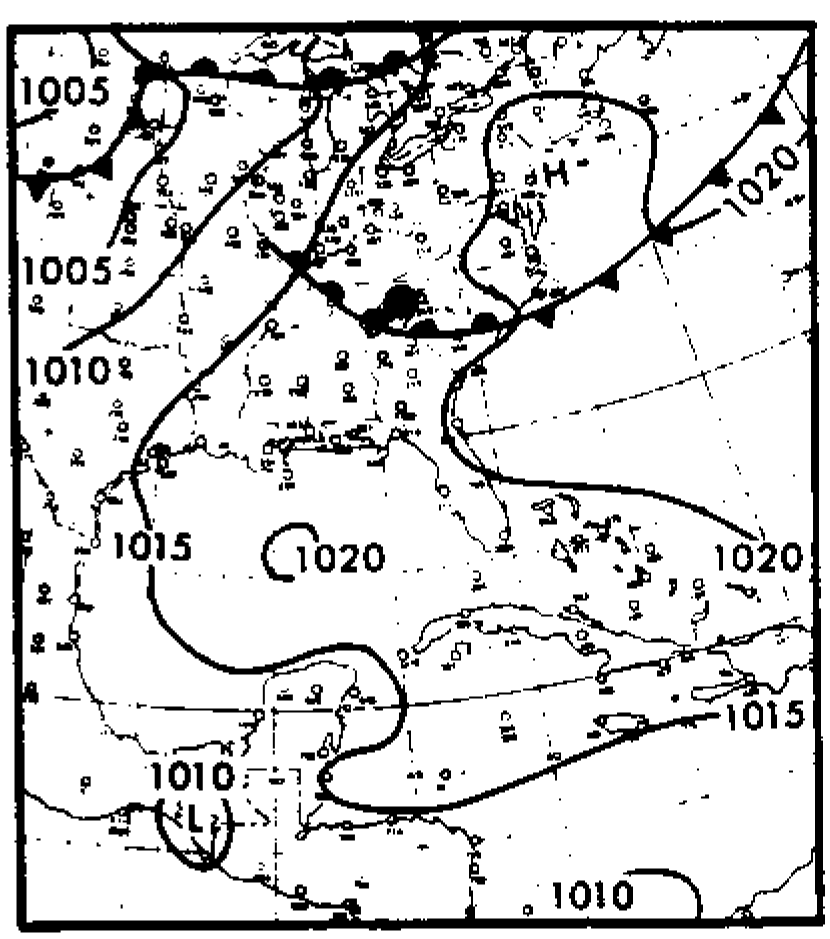
Approximate terrain elevations were determined for most of the storms in table 1. Elevations ranged from 700 ft to over 4,000 ft. A unique rainfall-elevation relation was not evident. This lack of relation supports a procedure that does not overemphasize the role of orography in short-duration rains. In addition to no correlation with orography, there was only a very slight geographical pattern discernible in the data of table 1.



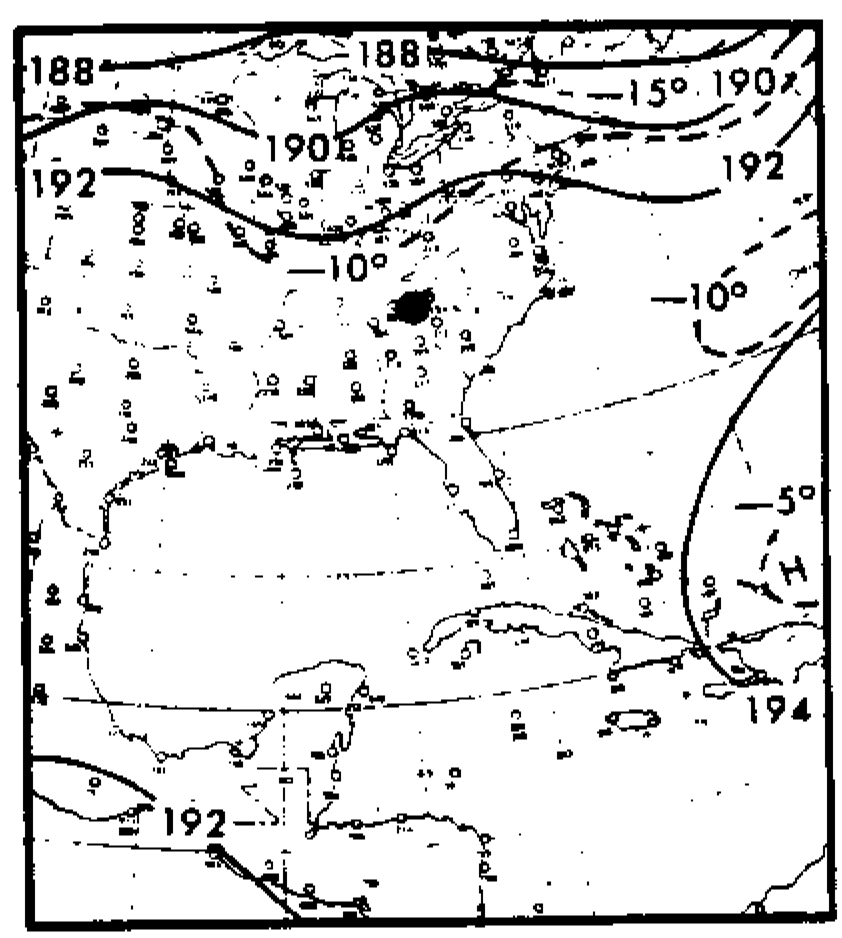
June 29, 1956 Sea Level 1230GMT



June 29, 1956 500 MB 1500GMT

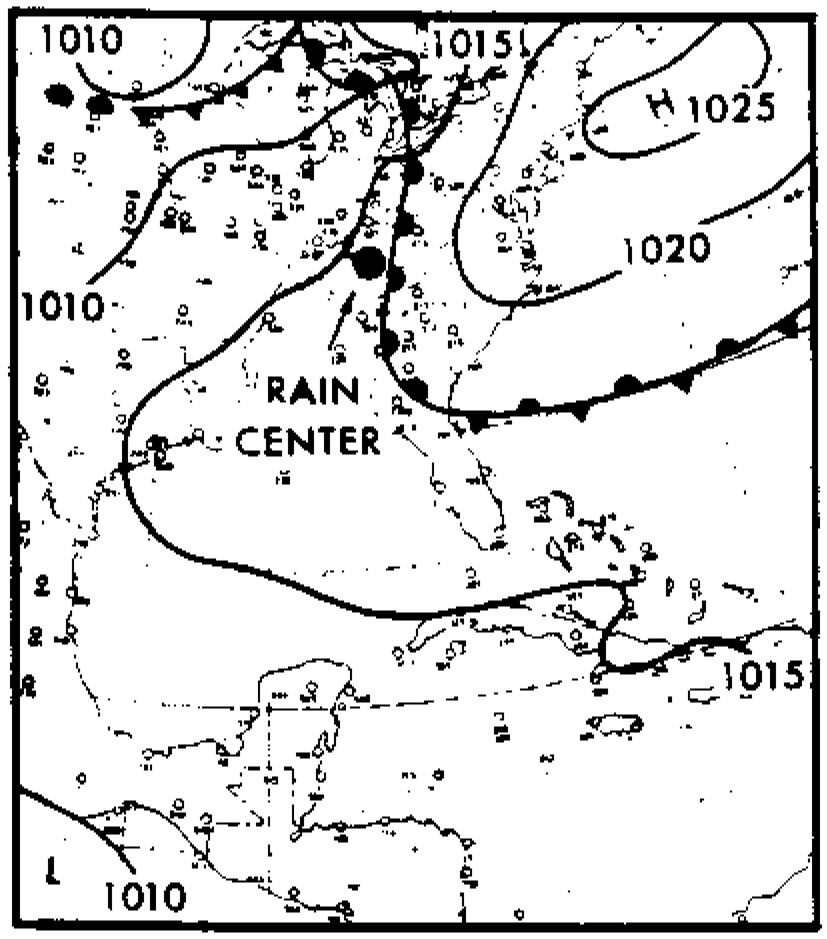


June 30, 1956 Sea Level 1230GMT

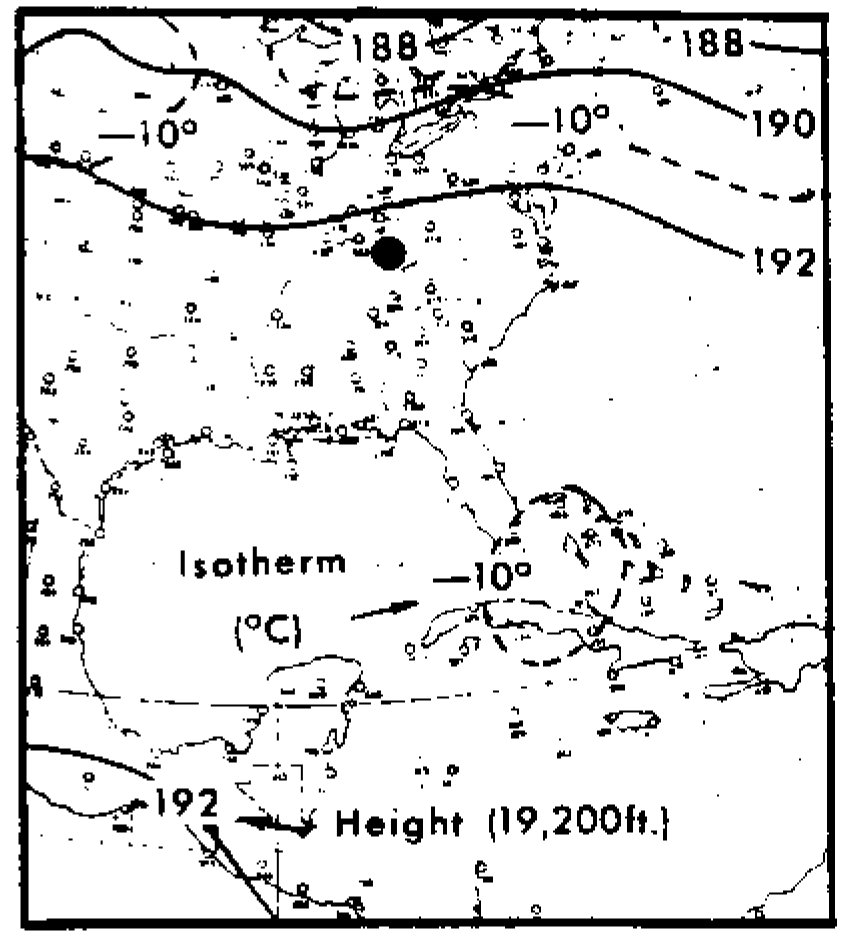


June 30, 1956 500 MB 1500GMT

Figure 3.--Surface and upper-air weather maps for June 30, 1956 storm in Cove Creek Basin, NC.



June 20, 1956 Sea Level 1230GMT



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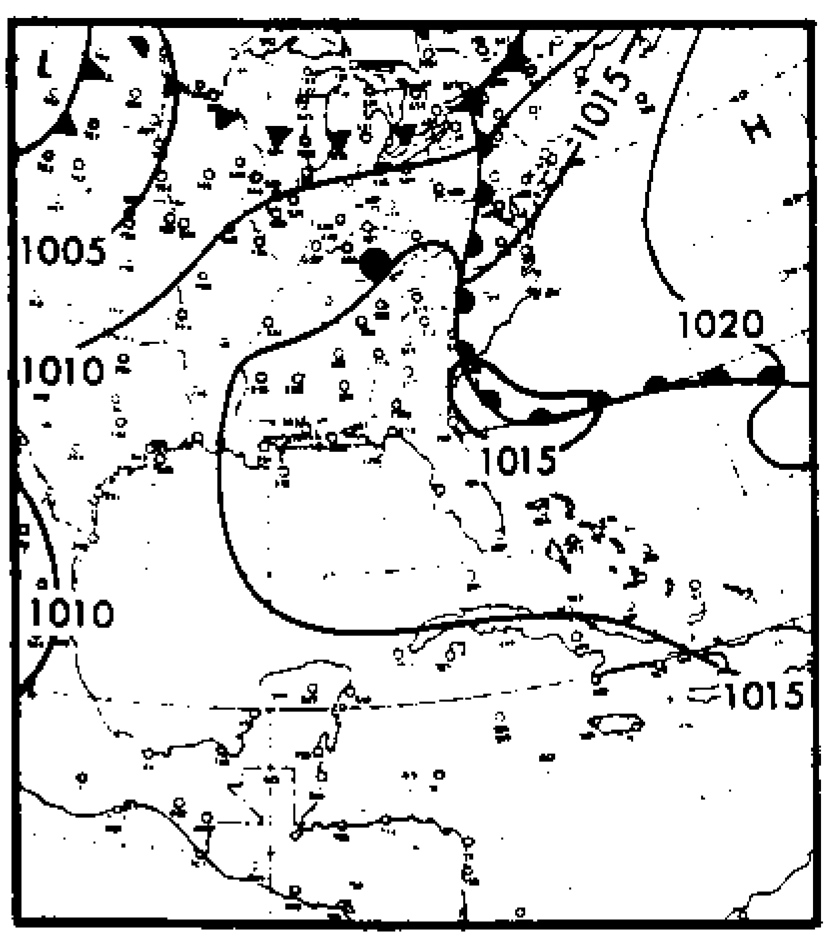
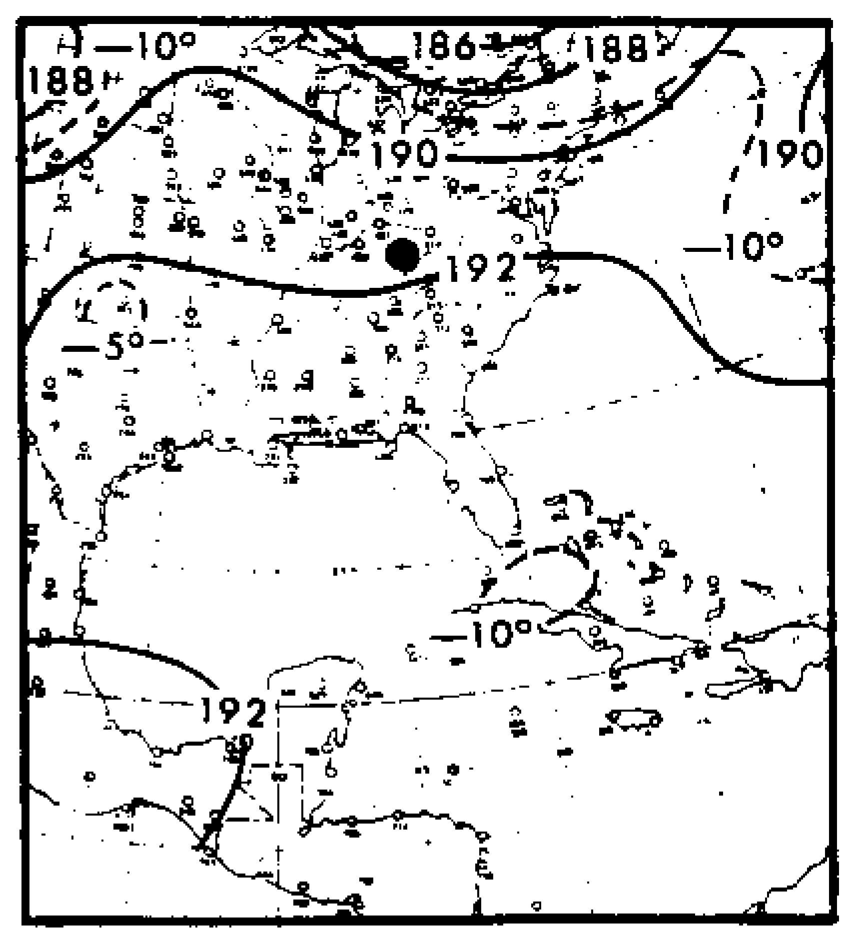


June 21, 1956 Sea Level 1230GMT



June 21, 1956 500 MB 1500GMT

Figure 4.--Surface and upper-air weather maps for June 21, 1956 for the storm near Manchester, KY.

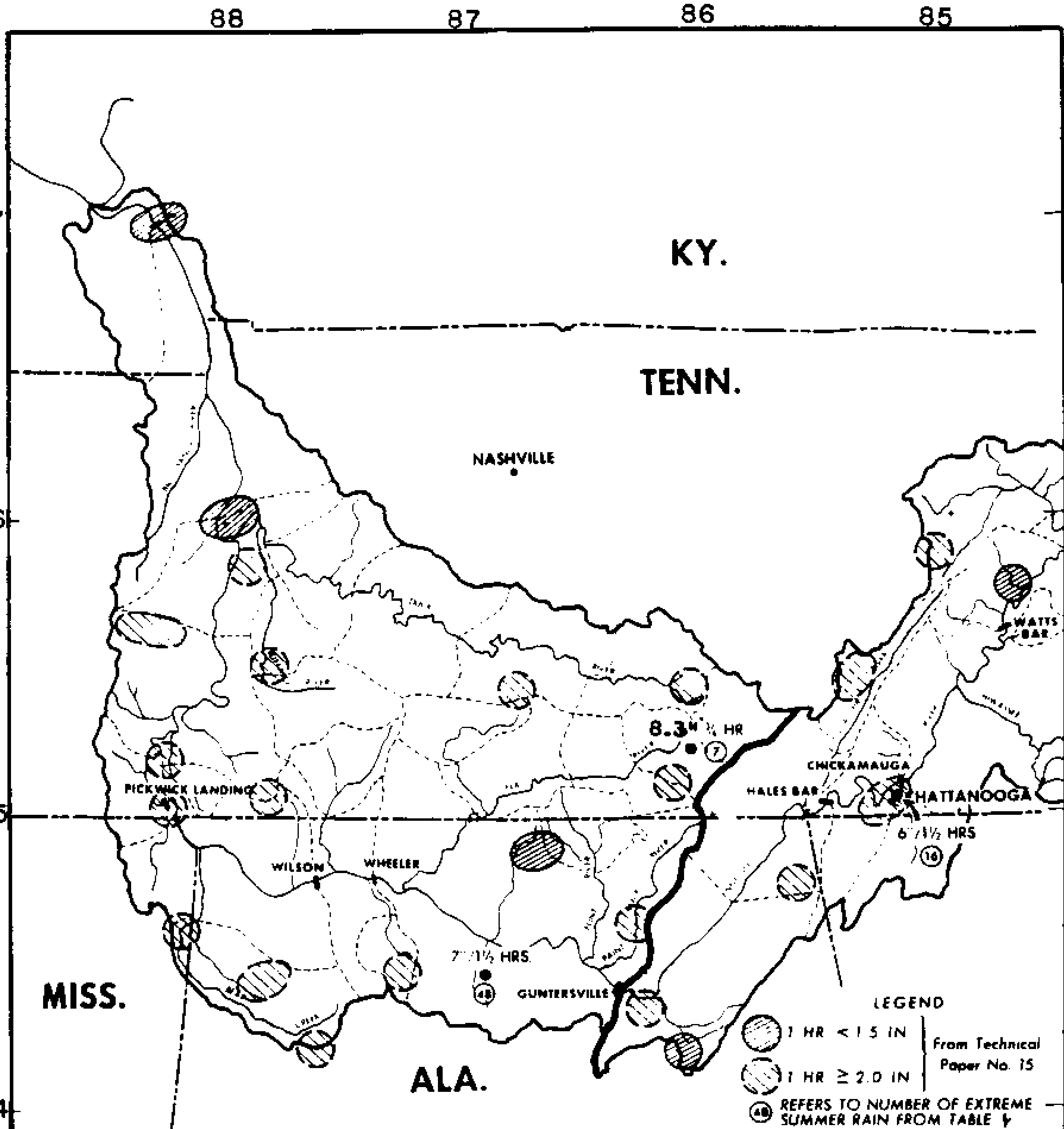


Figure 5.--Maximum observed 1-hr rains over western Tennessee River watershed (note overlap of eastern region shown in fig. 6).

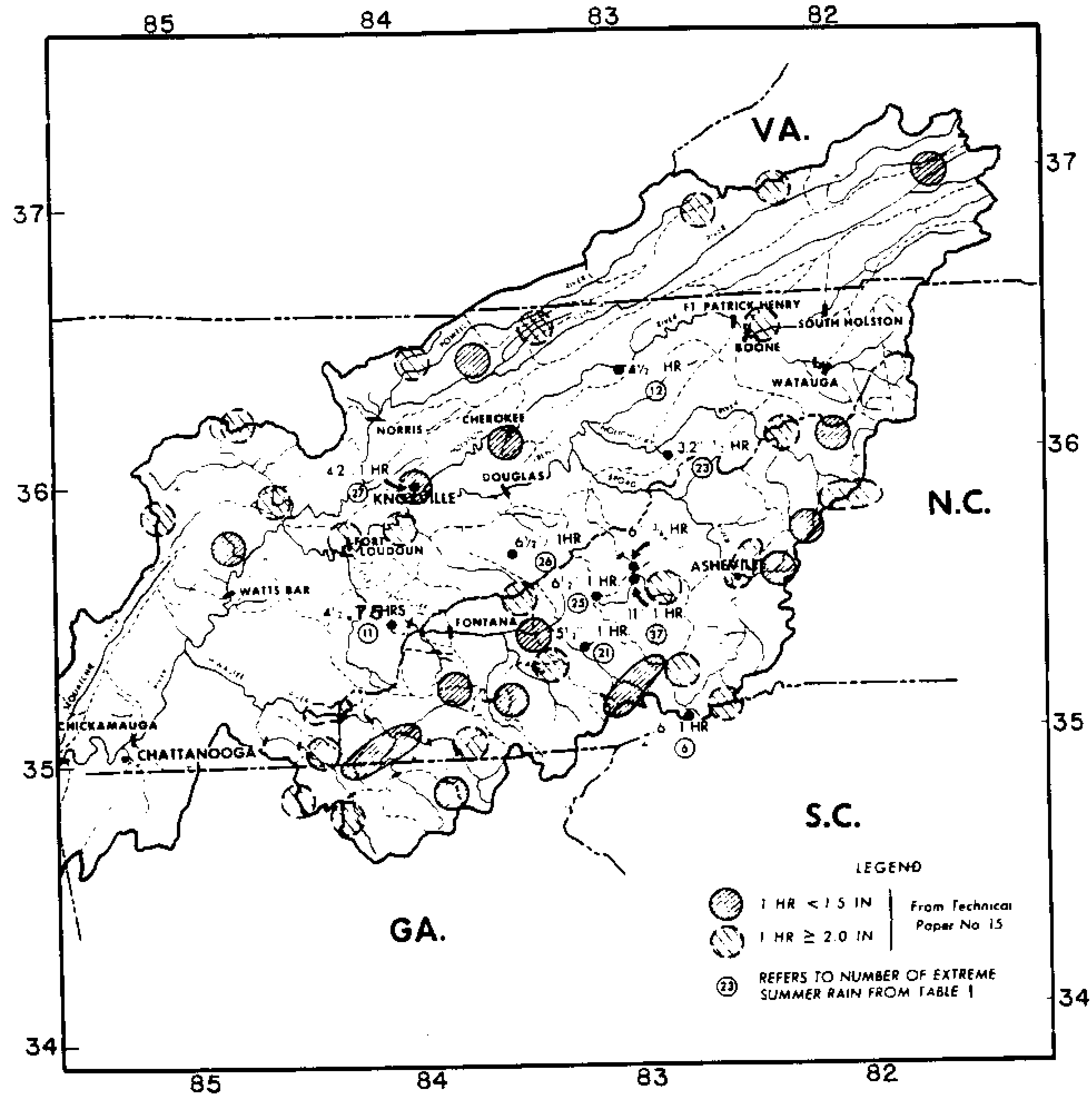


Figure 6.--Maximum observed 1-hr rains over eastern Tennessee River watershed.

Some of the more important values from table 1 were plotted in figures 5 and 6. Also shown on these figures are areas of maximum 1-hr rains obtained from Technical Paper No. 15 (U.S. Weather Bureau 1956). In order to reveal any possible regional differences the amounts are categorized into those exceeding 2 in. and those less than 1.5 in. in a 1-hr duration. There is no clear-cut regional preference. There is some slight tendency of rainfall areas with greater than 2 in. occurring along the southern boundary and in the mountainous east than in other regions. These factors and examination of maximum 1-hr amounts in major storms suggest that a very slight gradient in short-duration rainfall exists with somewhat greater values in the rougher terrain. In figures 5 and 6, rainfalls from TP 15 obtained from single stations are shown by circular symbols, while rainfall events from groups of stations are indicated by elliptical symbols.

Maximum 24-hr rains obtained from Technical Paper No. 16 (Jennings 1952) over the eastern, more mountainous portion of the Tennessee River watershed were plotted and analyzed for two rainfall categories; 24-hr rains in excess of 8 in., and those less than 4 in. On this basis, generalized areas of greatest or least orographic potential were outlined as shown in figure 7. The effects of upslope and broadscale sheltering are clearly indicated. These effects are discussed more thoroughly later in this chapter.

2.1.4 Intense Short-Duration Rains Throughout the Eastern United States

Intense small-area short-duration storms were extracted from over 600 storm studies prepared in "Storm Rainfall for the United States" (U.S. Army Corps of Engineers 1945-). The pertinent storms for assessing intense small-area rains were all cases of 6-hr 10-mi^2 rainfall of 10 in. or more (table 2). Particular attention was given to those cases exceeding 15 in. in 6 hr, and to those rainfall amounts less than 15 in. that would later be greatly maximized due to a larger moisture adjustment. In addition, all cases listed in "Storm Rainfall" with durations shorter than 6 hr were summarized. The locations of some of the more important maximum values of table 2 are shown in figure 8. Both observed and moisture-maximized values are shown.

Again, as with the intense storms listed in table 1, no single clearly defined storm type emerges from the examination of the meteorological descriptions associated with these rainfalls. Suffice it to say the Smethport, PA storm of July 17-18, 1942, with its characteristics of lasting through the night and being part of a larger area of thunderstorms, while concentrating the rain over a fixed area, single it out as most clearly depicting the PMP storm type for the TVA region.

2.1.5 Clues From Larger Area Storms

Since storms like the Smethport storm are such a rarity, we are forced to turn to storms producing less phenomenal rainfall totals in order to further characterize the PMP storm type. One criterion used for selecting summer (or summer-type) storms which produced large volumes of rainfall in or near the Tennessee River watershed was the number of stations which simultaneously recorded maximum 24-hr rains. Weather Bureau Technical Paper No. 16 (Jennings 1952) together with a survey of data more recently available in a computer compatible form (Peck et al. 1977) provides a convenient summary. From this survey involving several hundred stations, nine significant storms were identified. These are listed in table 3, which gives the storm date and the

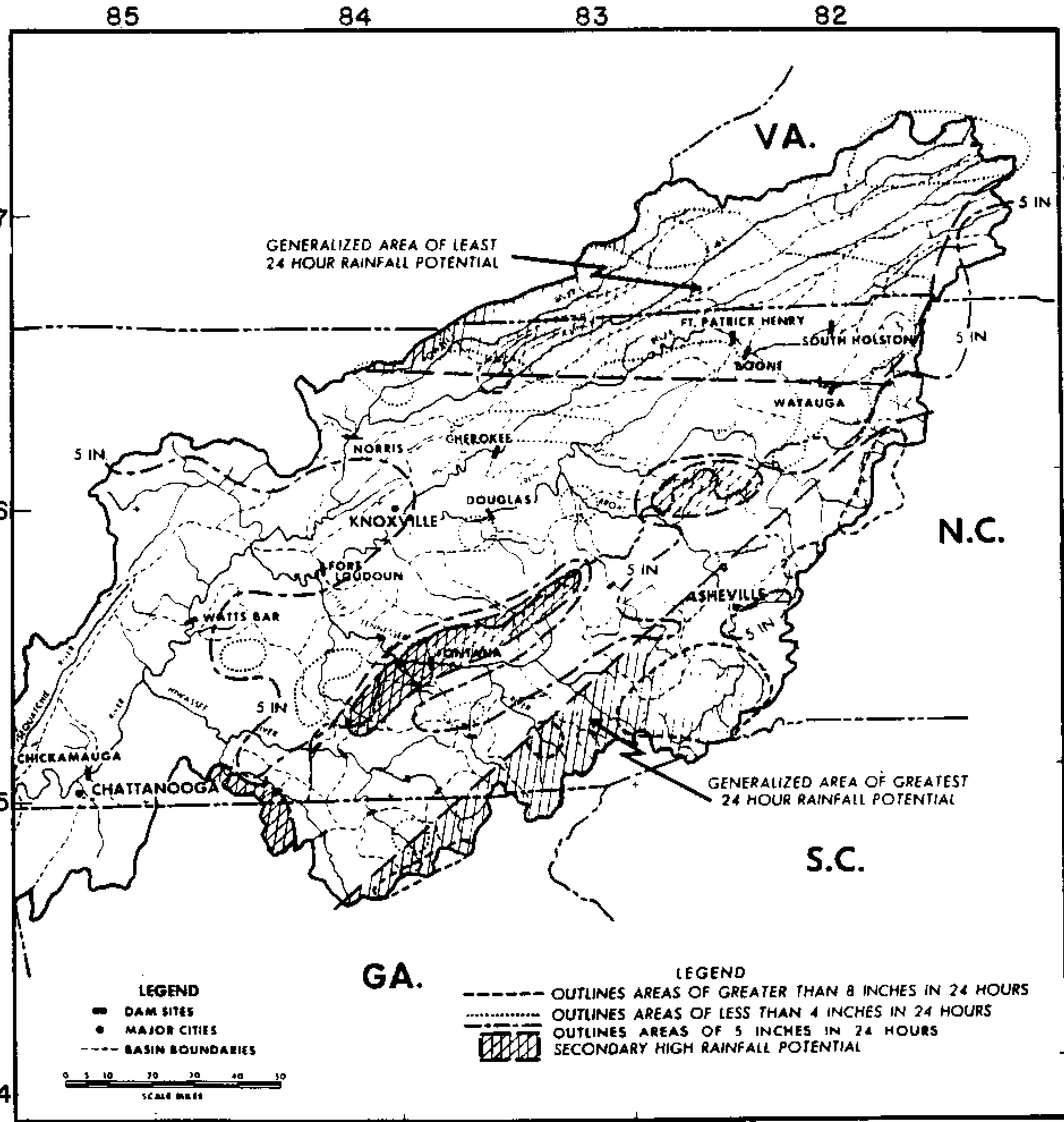


Figure 7.--Areas of greatest and least 24-hr rainfall potential, based on station rainfall data.

Table 2.--United States rainfall occurrences equaling or exceeding 10 in. in 6 hr*

Date	Observed amount (in.) 6 hr 10 mi^2		Moisture maximization (percent)
June 13-17, 1886	11.5	Alexandria, LA	16
June 23-27, 1891	10.4	Larabee, IA	28
June 4-7, 1896	12.0	Greeley, NE	55
July 26-29, 1897	13.0	Jewell, MD	41
June 12-13, 1907	6.2 (3 hr)	Fort Meade, SD	28
July 18-23, 1909	10.5	Ironwood, MI	34
July 18-23, 1909	10.5	Beaulieu, MN	34
Aug. 28-31, 1911	14.9	St. George, GA	21
Aug. 31-Sept. 1, 1914	12.6	Cooper, MI	55
Aug. 1-3, 1915	12.9	St. Petersburg, FL	16
Sept. 28-30, 1915	10.1	Franklinton, LA	16
July 5-10, 1916	15.9	Bonifay, FL	10**
June 2-6, 1921	10.4	Pueblo, CO	51**
June 17-21, 1921	10.5	Springbrook, MT	31
Sept. 8-10, 1921	22.4	Thrall (Taylor) TX	5
July 9-12, 1922	10.8	Grant City, MO	34
Oct. 4-11, 1924	13.6	New Smyrna, FL	21
Sept. 11-16, 1926	13.4	Neosho Falls, KS	34
Sept. 17-19, 1926	15.1	Boyden, IA	34
April 12-16, 1927	13.8	Jeff.-Plaq.Drain. Dist., LA	22
March 11-16, 1929	14.0	Elba, AL	34
May 25-30, 1929	11.3	Henly, TX	10
June 20-July 2, 1932	13.3	State Fish Hatchery, TX	16
Aug. 30-Sept. 5, 1932	10.0	Fairfield, TX	10
April 3-4, 1934	17.3	Cheyenne, OK	49
May 2-7, 1935	10.6	Melville, LA	22
May 16-20, 1935	13.8	Simmesport, LA	28**
May 30-31, 1935	20.6	Cherry Creek, CO	63
June 27-July 4, 1936	14.0	Bebe, TX	0
Sept. 14-18, 1936	16.0	Broome, TX	5
May 30-31, 1938	10.0	Sharon Springs, KS	55
July 19-25, 1938	11.5	Eldorado, TX	16
Aug. 12-15, 1938	10.9	Koll, LA	10
May 25, 1939	8.2 (2 hr)	Lebanon, VA	22**
June 19-20, 1939	18.8	Snyder, TX	23
July 4-5, 1939	18.6 (3 hr)	Simpson P.O., KY	16
July 4-5, 1939	20.0	Simpson P.O., KY	16
Aug. 21, 1939	9.5 (3hr)	Baldwin, ME	5
June 3-4, 1940	13.0	Grant Township, NE	63
June 28-30, 1940	11.0	Engle, TX	5

Table 2.--United States rainfall occurrences equaling or exceeding 10 in. in 6 hr* (continued)

Date	Observed amount (in.) 6 hr 10 mi^2		Moisture maximization (percent)
Sept. 1, 1940	20.1	Ewan, NJ	22
Sept. 2-6, 1940	18.4	Hallett, OK	41
May 22, 1941	6.5 (3 hr)	Plainville, IL	63
Oct. 17-22, 1941	12.9	Trenton, FL	16
April 14-17, 1942	13.1	Green Acres City, FL	48
July 17-18, 1942	24.7	Smethport, PA	10
May 12-20, 1943	15.9	Near Mounds, OK	28
June 5-7, 1943	14.2	Silver Lake, TX	16
July 27-29, 1943	10.7	Devers, TX	10
Aug. 4-5, 1943	11.1	Glenville, WV	16
June 10-13, 1944	13.4	Stanton, NE	41
July 9, 1945	9.1 (4 hr)	Easton, PA	80
Aug. 26-29, 1945	10.1	Hockley, TX	16
Aug. 12-15, 1946	10.6	Cole Camp, MO	21
Sept. 26-27, 1946	15.8	San Antonio, TX	10
June 18-23, 1947	11.5	Holt, MO	16
Aug. 27-28, 1947	13.8	Wickes, AK	28
Aug. 24-27, 1947	10.9	Dallas, TX	10
June 23-24, 1948	13.2	Del Rio, TX	35**
Sept. 3-7, 1950	16.0	Yankeetown, FL	10
June 23-28, 1954	16.0	Vic Pierce, TX	30**
June 23-24, 1963	14.6	David City, NE	34
June 17, 1965	11.5	Near Lamar, CO	28
August 12-13, 1966	11.4	Greeley, NE	28
August 19-20, 1969	14.2	Tyro, VA	5
October 10-11, 1973	16.9	Enid, OK	10

* A few cases of storms less than 6 hr duration are included.
** Revised moisture maximization adjustments obtained from HMR No. 55 (Miller et al. 1984)

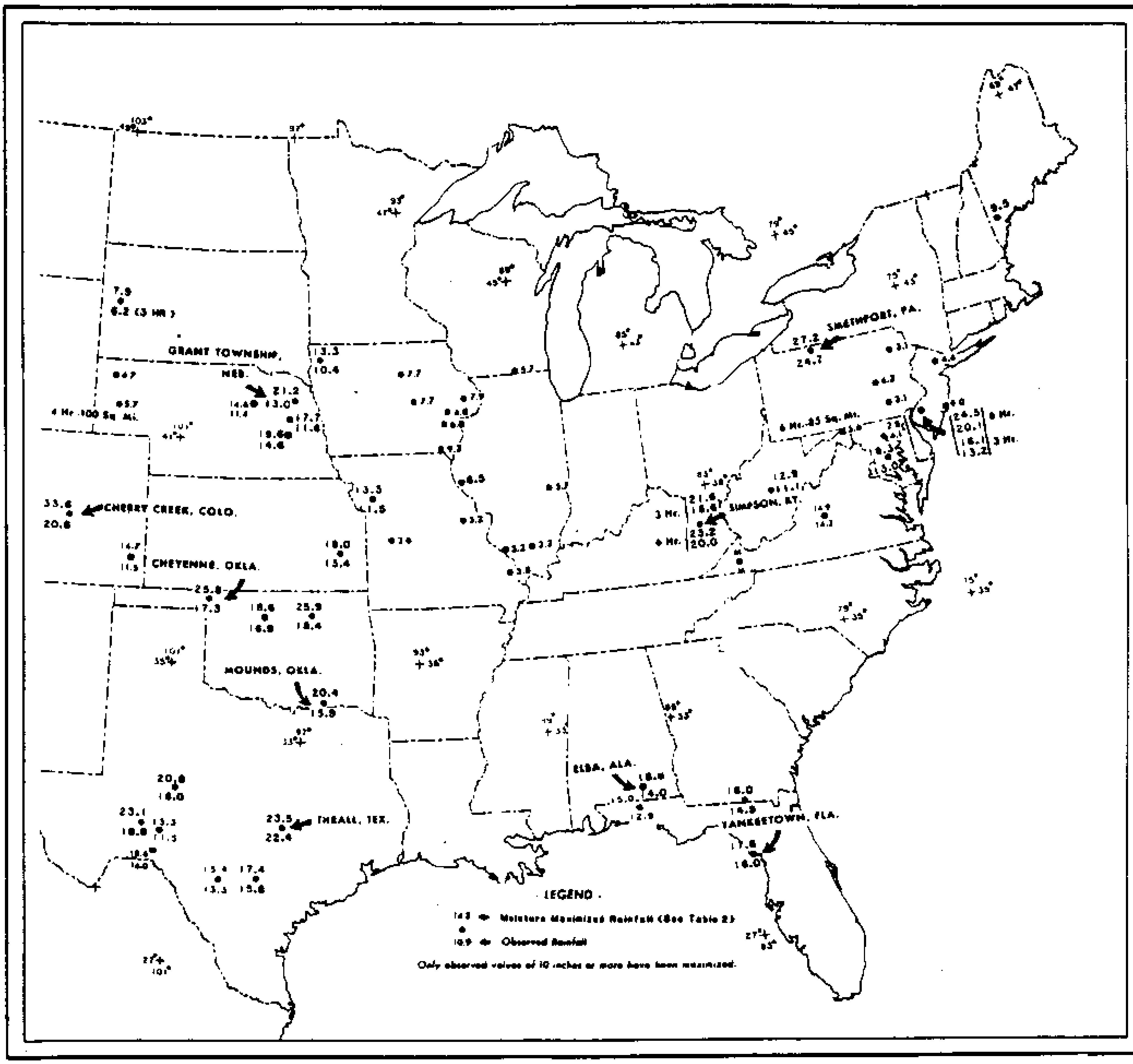
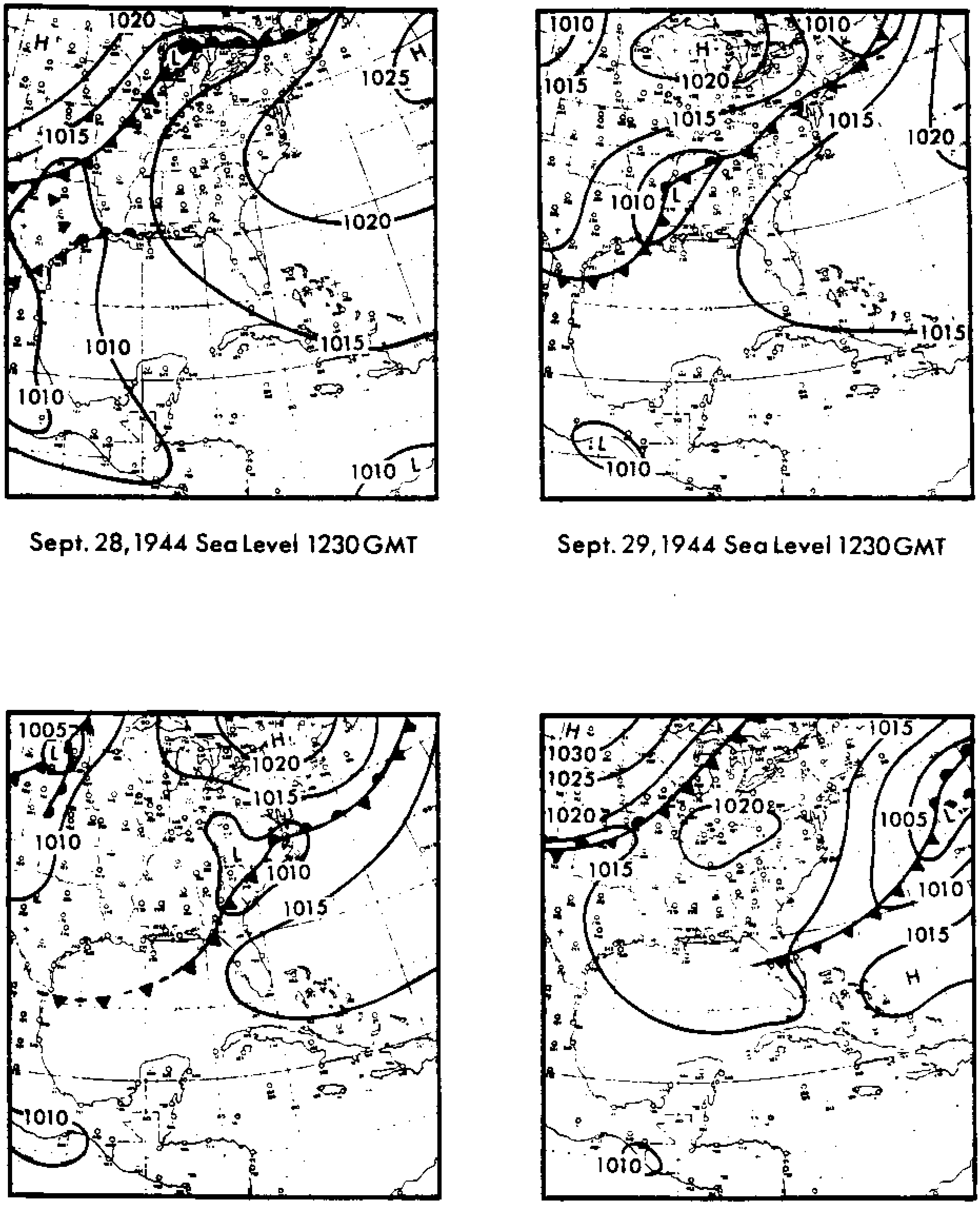


Figure 8.—Observed and moisture maximized 6-hr 10-mi^2 rainfall values from Storm Rainfall in the United States (U.S. Army 1945 -).

number of stations recording their maximum 24-hr rains during this period. Weather maps for two of the storms in table 3 (September 1944 and June 1949) are shown in figures 9 and 10. Figures 9 and 10 indicate that significant cold and warm fronts are likely to be associated with the rainfall from these storms.

The fact that most of the above storms do not occur in the midsummer period is of interest. They are close enough to midsummer to draw upon high moisture values, yet close enough to the cooler seasons to utilize more efficient rain-enhancing mechanisms, such as the convergence associated with significant fronts, etc. Since rain-enhanced mechanisms are more frequent in the vicinity of the



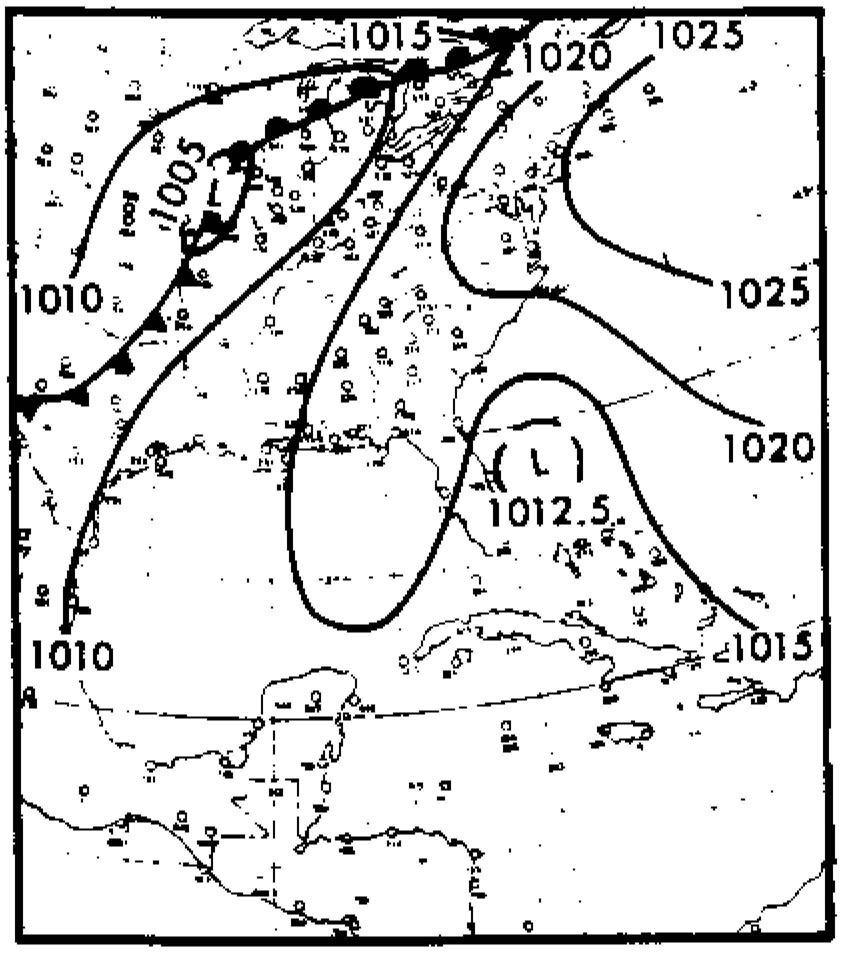
Sept. 28, 1944 Sea Level 1230 GMT

Sept. 29, 1944 Sea Level 1230 GMT

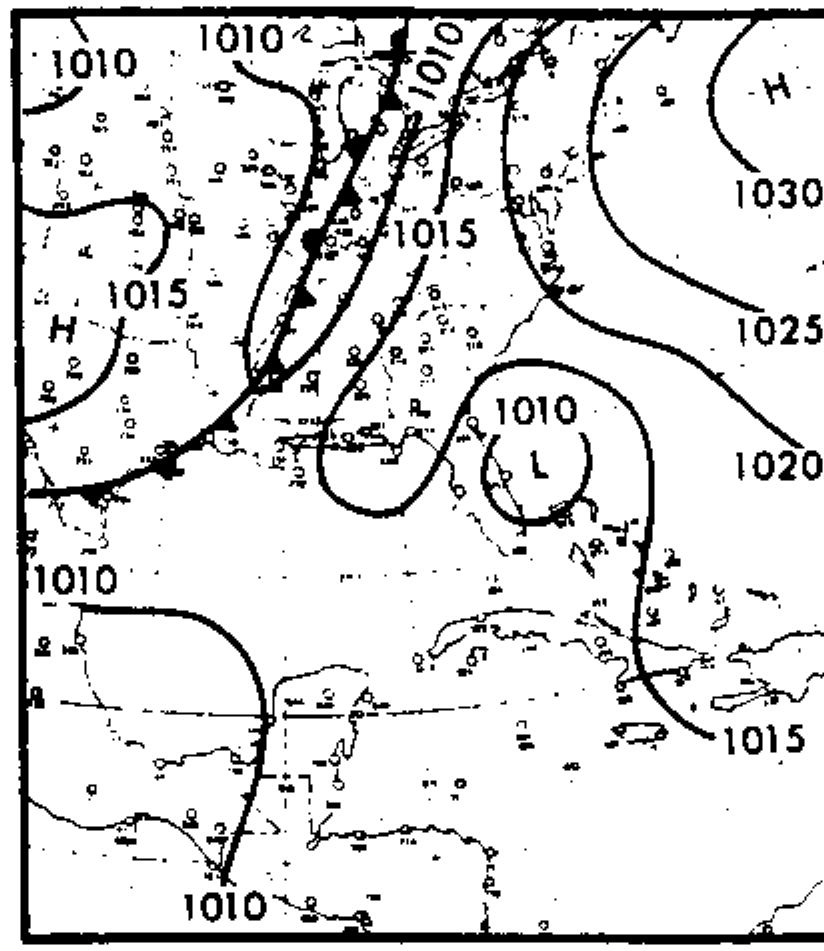
Sept. 30, 1944 Sea Level 1230 GMT

Oct. 1, 1944 Sea Level 1230 GMT

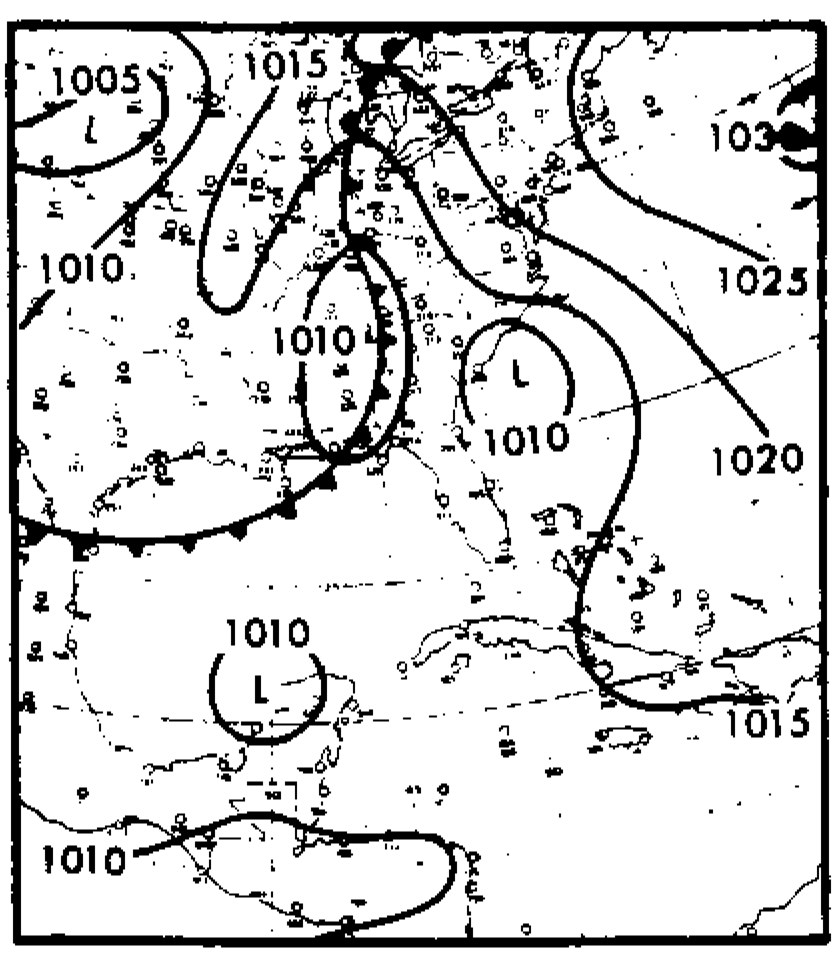
Figure 9.—Surface weather maps for September 28–October 1, 1944.



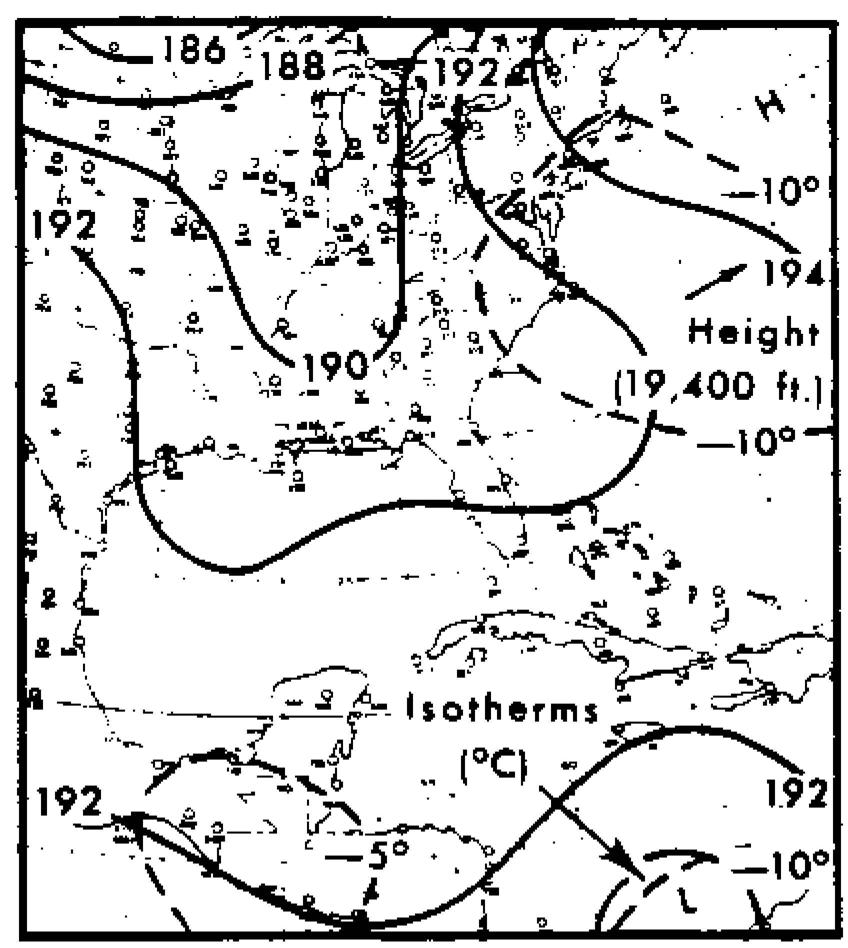
June 14, 1949 Sea Level 1230 GMT



June 15, 1949 Sea Level 1230 GMT



June 16, 1949 Sea Level 1230 GMT



June 16, 1949 500 MB 0300 GMT

Figure 10.--Surface and upper-air weather maps for June 14-16, 1949.

Table 3.--Storms producing maximum 24-hr rains simultaneously at stations in and near the Tennessee River watershed.

Storm Date	No. of Stations
August 13-14, 1940	16
August 29-30, 1940	16
Sept. 27-30, 1944	28
June 27-29, 1947	5
June 15-16, 1949	11
October 30-31, 1949	7
March 21-22, 1955	4
March 11-12, 1963	7
Sept. 28-29, 1964	6

Tennessee River watershed in the transition seasons, it is at these times that one is more apt to find a greater number of storms that have the "longer-lasting" characteristic of the summer PMP-type storm. Thunderstorms are involved in these transition season storms, but their rain-producing capabilities are somewhat limited by not being able to draw upon moisture values as high as is possible in midsummer.

An example of a late-fall storm which produced intense rainfall values is that of November 18-19, 1957 (Kleinsasser 1958). This storm produced 9 in. of rain in 2 hr (table 1) over 200 mi^2. The moisture charge, instability and air-inflow rate in this storm were similar to those in other heavy rain-producing situations. A slowing of the movement of the squall line apparently resulted in an unusual concentration of heavy rain by prolonging the rainfall in a fixed area. Such a storm, though a late-season one, embodies features of the PMP storm type, since intense thunderstorm produced rains were part of a longer-lasting and larger rainfall area.

The Tennessee River watershed lies far enough north that mechanisms for rain production such as squall lines common in the transitional season are also possible (although much less frequent) in the midsummer months. When one or more such "mechanisms" operates in summer over a geographically-fixed area, with moisture near maximum, a Smethport type PMP storm may be the result.

2.1.6 Thunderstorm Climatology and the Diurnal Character of Thunderstorm Rainfall

The PMP thunderstorm day is envisioned as continued repetition of thunderstorms throughout a 24-hr period. Such a situation requires a continued transport of high moisture into the area of thunderstorm activity and a near stationary triggering mechanism. For the Tennessee River basin, high moisture would generally require winds with a southern component since the moisture source is the Gulf of Mexico. For some areas, such as the westward-facing slopes of the Smokies in Virginia, a more indirect influx of Gulf of Mexico moisture by-passing the mountains and then veering to come from a westerly direction would provide the most effective utilization of existing ground slopes.

A summation of thunderstorm statistics for typical stations in the basin helps to clarify certain characteristics of the PMP type of thunderstorm situation.

Consideration of only summer data on thunderstorms can be misleading. Figure 11 shows the average monthly variation of thunderstorm days at selected Tennessee stations. Data on thunderstorms at Oak Ridge were not available beyond 1964. Figure 12 shows the average daily amount of rainfall on days with thunderstorms for these same stations. The less frequent cooler-season storms which show more average daily rain are in one sense more typical of the PMP type since the cooler-season thunderstorms occur in longer duration rain situations.

2.1.6.1 Diurnal Variation of Thunderstorms as Related to the PMP-Type Storm. Most thunderstorms in the eastern United States occur in the afternoon or evening. However, this diurnal variation does not necessarily apply to the PMP type. Most afternoon thunderstorms last an hour or less, and even the extreme ones generally last less than 3 hr. Studies (Changnon 1968, Sangster 1967, and Bonner et al. 1968) emphasized the complexity of the diurnal variation of thunderstorm problems as related to extreme rainfall.

Most Tennessee River watershed summer thunderstorms (those summarized in fig. 11 and 12) are of the insolation, short-lived type. Insolation, or solar radiation received at the earth's surface, is the mechanism often given as the cause of isolated local thunderstorm activity. One trend that can be found in the Tennessee River watershed thunderstorm data is the decrease in importance of the insolation factors as the intensity and longevity of the thunderstorm increase.

2.1.6.2 Chattanooga Thunderstorm Diurnal Characteristics. The hourly distribution of precipitation for Chattanooga was summarized for all thunderstorm days in the March-October season during the 1955-1982 28-yr period. A threshold of at least 0.5 in. of rain in a 24-hr period was required to make the data meaningful. Figure 13A summarized the frequency of occurrence of 0.25 in. in any hour for all cases with a daily total of 0.5 in. or more, while figure 13B does so for cases with daily rainfall amounts of 2 in. or more. A decreased effect of the diurnal heating factor is suggested as the heavier rainfall cases are considered. This trend away from the importance of insolation as the thunderstorm intensity increases becomes more evident as one considers the most extreme occurrences.

2.1.6.3 Diurnal Characteristics of Extreme United States Rains. The Tennessee River watershed storm of June 13, 1924 (table 1) began before midnight and lasted into the early morning hours. The storm of July 26, 1960, at Grizzle Creek, GA, occurred mostly between 10 p.m. and 1 a.m. Study of the Smethport, PA storm of July 17-18, 1942, indicates that most rain in this storm occurred between midnight and noon. Thus, the usual diurnal characteristics of thunderstorm rainfall appear to be lost in the really big summer thunderstorms. Atmospheric mechanisms contributing to the fixing and prolonging of the rain assume more importance in such storms so that the diurnal heating effect is overwhelmed.

A study was made of the hours of occurrence of the intense rainstorms listed in table 2. Although many of these rains started as showers in the afternoon, the modal time was from 1 to 2 a.m. Since this sample included storms from the Plains states, where nocturnal thunderstorms are common (Means 1952), separate evaluation was made using only storms east of the Mississippi River. Results were similar, with 2 to 4 a.m. being the modal time of rainfall occurrences. These extreme rains more nearly represent the PMP storm type in terms of the loss of afternoon diurnal control. Because of the nocturnal frequency of such storms,

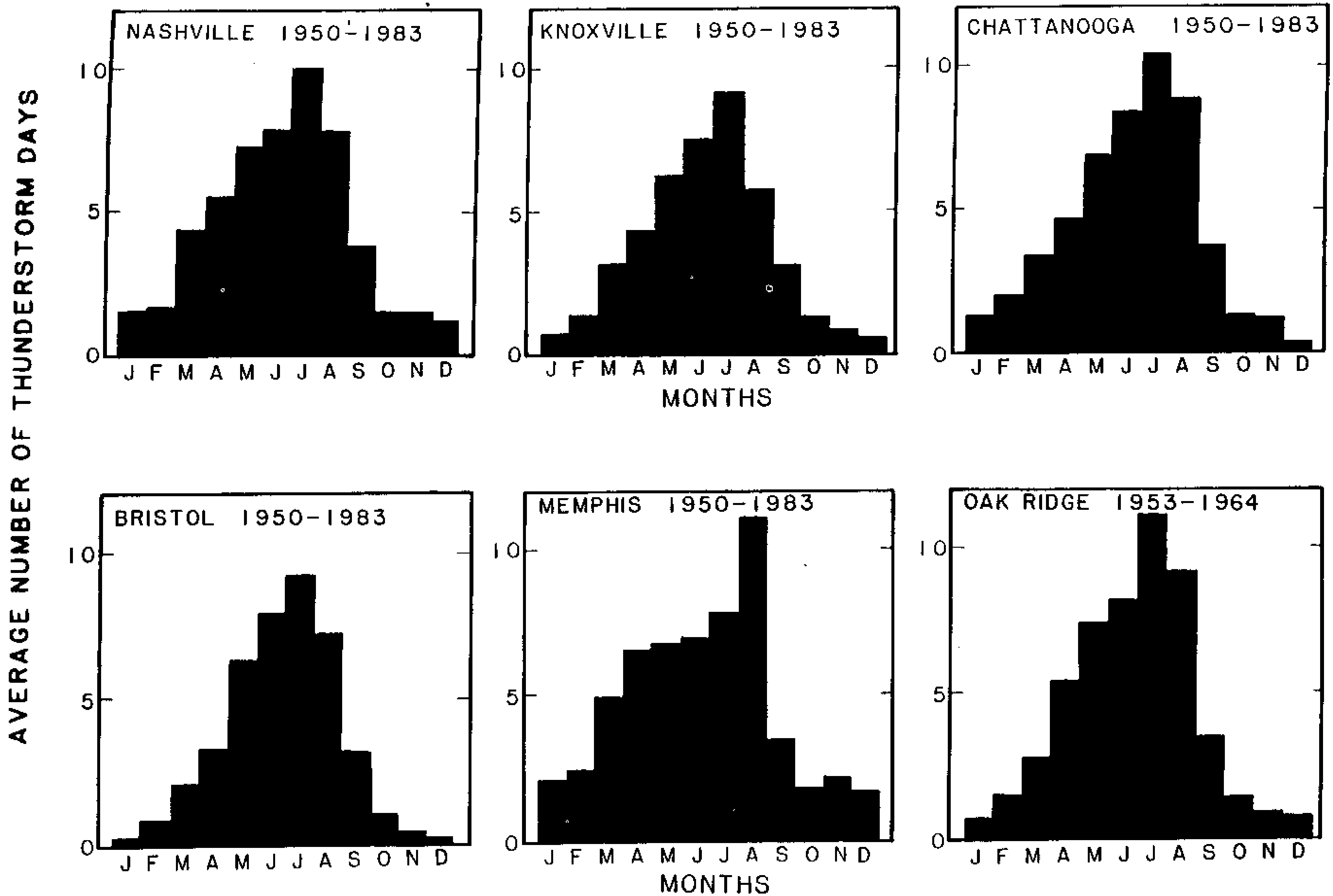


Figure 11.--Monthly variation of thunderstorms at Tennessee stations.

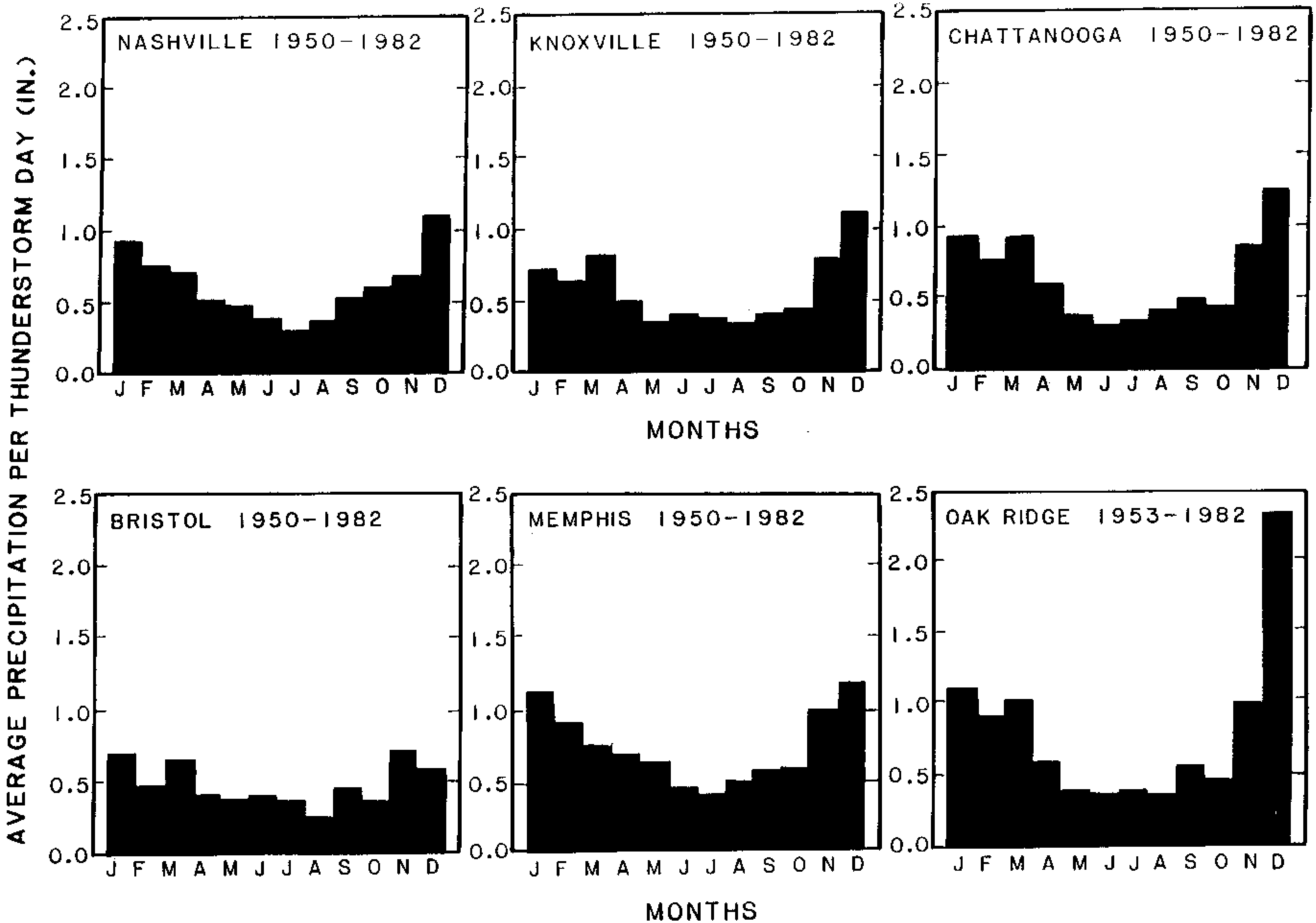


Figure 12.--Monthly variation of average daily precipitation on days with thunderstorms.

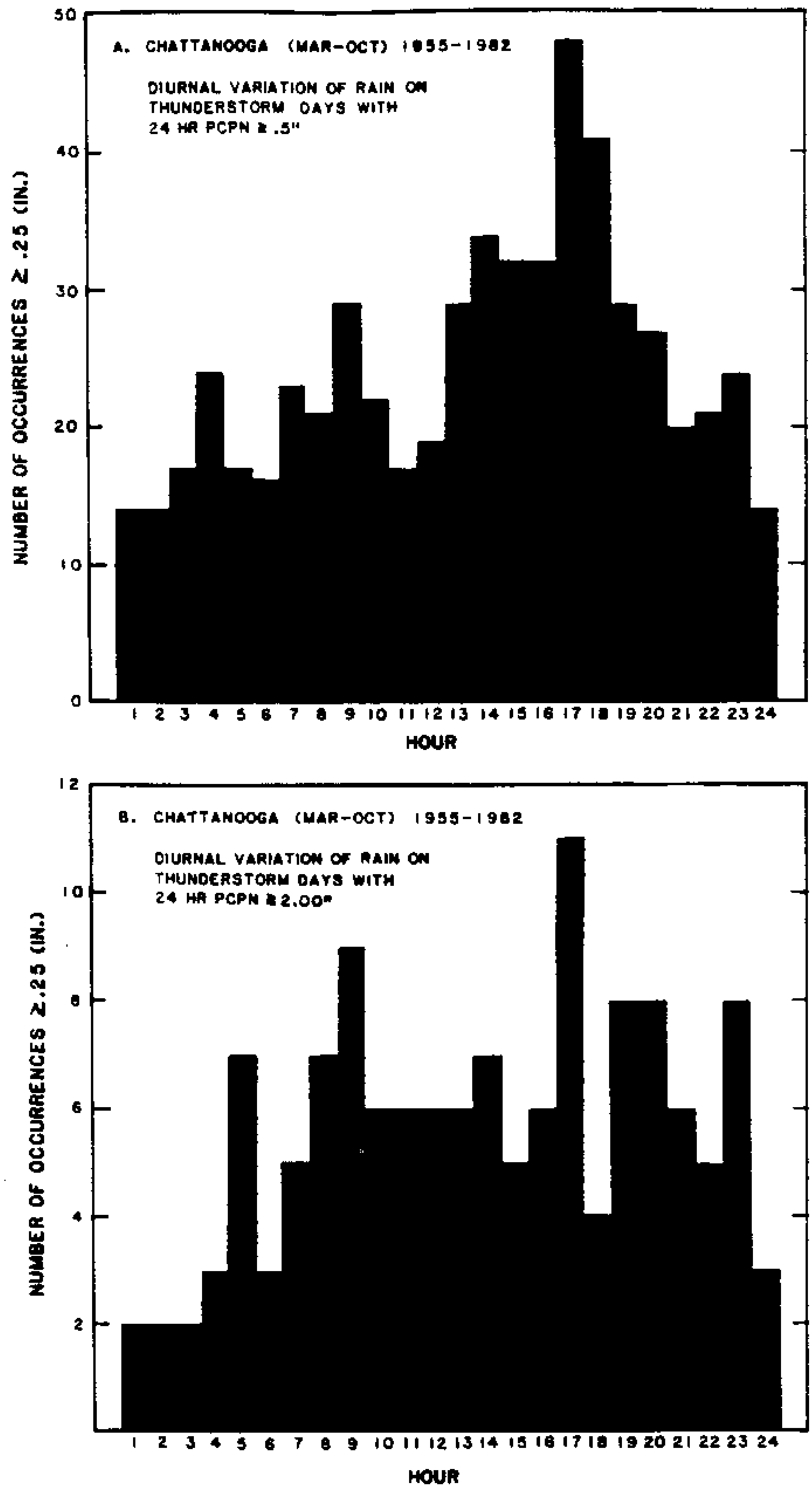


Figure 13.--Diurnal variation of the thunderstorm rainfall at Chattanooga on days with (A) ½ in. or more and (B) 2 in. or more.

a convergence mechanism that overwhelms insolation and other influences appears to predominate in the more extreme rains and in the PMP storm, especially.

2.1.6.4 Conclusions on Diurnal Characteristics. We conclude from the discussion above that the diurnal characteristics common to many thunderstorms both in and outside the Tennessee River watershed does not need to be adhered to in the PMP situation. In the PMP and the TVA storms, the rainfall will extend through and perhaps maximize during the nighttime hours. In the procedure that follows in this and subsequent chapters, allowance is partially made for the more characteristic abbreviated thunderstorm by allowing a TVA level thunderstorm to prevail for as short as 3 hr.

2.1.7 Joining of Thunderstorms as Related to PMP-Type Storms

Eyewitnesses typically describe extreme rain situations in terms of two or more clouds (storms) "coming together." Table 4 compiled from TVA storm-survey files, summarizes a group of eyewitness accounts of such storms which have occurred in Tennessee and nearby states. These observations are not necessarily restricted to daylight hours since the frequency of lightning in extreme rainfall occurrences permit such observations at night. The use of infrared satellite photos also permit such observations at night. The merging phenomenon, which has also been observed by radar, occurs rather frequently, judging from the reported observance of such occurrences.

Outstanding storms in other parts of the country that involve merging of cloud cells have been similarly described by eyewitnesses. For example, eyewitnesses of a storm near Morgan, UT, on August 16, 1958, that reportedly produced 7 in. of rain in an hour, stated that two clouds appeared to meet right over the valley. Another example is quoted from the observers' notes after a Campo, CA, storm of August 12, 1899, in which an estimated 11 1/2 in. occurred in 80 min; "... and then another cloud came up and the one that had part pased [sic] over drew back and the two came togather [sic] and it pourd [sic] down whole watter [sic] nearly." Another observer had this to say about the Catskill, NY storm of July 26, 1819, which dumped 18 in. of rain in 7 1/2 hr:

> "...about half past 5 another dense and black cloud accompanied by a fresh wind arose from the southwest. About the same time or immediately after, a very thick and dark cloud rose up rapidly from the northeast. They met immediately over the town."

Eyewitnesses of the outstanding Smethport, PA storm also spoke of stupendous masses of clouds approaching the area from several directions. Fritsch and Maddox (1981) discuss the changes in winds produced by large mid-latitude convective complexes. They concluded that the changes in the winds in the troposphere and lower stratosphere are rather substantial. In addition, these convective systems could also influence the structure of subsequent convective cloud growth.

Two things were noted about these accounts. First, they usually refer to thunderstorm occurrences in areas that have hills and valleys in close proximity. Second, they concern thunderstorm situations that produced unusually heavy rains.

Table 4.--Storms in the Tennessee River watershed with eyewitness accounts of two storms meeting or coming together

Location	(Coordinates)	Date	Description
Saltville, VA	36°53' 81°46'	7/5/36	"...two storms came together and one man said he thought--- three storm clouds...all came together at the same time"
Speer Ferry, VA	36°39' 82°45'	7/17/36	"...apparently two clouds met, one approaching from the North and the other from the west"
Bulls Gap (nr.) TN	36°15' 83°05'	7/30/37	"...described the storm as the meeting of 3 or 4 clouds from as many directions"
Hayesville (nr.) NC	35°05' 82°50'	7/7/38	"...observed the approach and meeting of two rain clouds, one from the NW and one from the east"
Winchester Springs (nr.) TN	35°14' 86°06'	7/8/38	"...rain came from two clouds, one approaching from the east and one from the west, which met just north of his house"
Lebabon, VA	36°54' 82°05'	5/25/39	"...two storm clouds approached from opposite directions, one from the SW and the other from the NE..."
Adamsville, TN	35°14' 88°24'	6/7/40	"...rain came from two clouds, one moving in and from the SW and one from the NW"
Rogersville, AL	36°22' 83°03'	7/8/40	"...and heavy rain lasted about 1 hr and resulted from the meeting of two clouds, one moving from the SW and one from the SE"
Sparta (nr.) TN	35°55' 85°28'	6/4/49	"The clouds appeared to meet (from east and west) at the top of Little Chatnut mountain..."
Dillard, GA	34°58' 83°55'	6/5/52	"...2 storms, one approaching from...the SW...and the other from...the NE, converged...just south of Dillard"
Grizzle Creek, GA	34°33' 84°04'	7/26/60	"Two clouds moved in from two different directions and met over this area and "the bottom dropped out"

One may conjecture on the meaning of such eyewitness accounts in connection with outstanding cloudbursts. It is possible that the nearly simultaneous occurrence on nearby slopes of two separate thunderstorms sets the stage. With the two gravity-aided cold outflows racing downhill, the resulting convergence sets off a new and more vigorous convective development as the two outflows approach or intermingle. The new thunderstorm development takes over, and the surrounding inflow entrains (pulls) the remnants of the initial thunderstorms into the new development. The new thunderstorm would presumably be extremely efficient since it would entrain into itself not only moist air (minimizing evaporation losses) but also residual, previously formed raindrops. This makes possible local rainfall rates of a magnitude exceeding rates computed by the usual theories which relate the convergence of water vapor to precipitation.

The discussion above has some bearing on the adoption of a storm similar to the one that occurred at Smethport as the PMP storm type for the Tennessee River watershed. The question arises as to whether such a storm is possible to the fullest extent throughout the Tennessee River watershed. Since it has been observed that the "clouds-coming-together" phenomenon is characteristically reported in areas with hills and valleys in close proximity, it apparently would not be realistic to postulate the occurrence of the Smethport type storm unadjusted in very flat regions. Therefore, a geographical distinction is made in applying the PMP-type storm (sect. 2.2).

2.1.8 Season of Small-Area PMP and TVA Precipitation

The discussion in sections 2.1.4 and 2.1.5 of major storms in the eastern United States suggests that major thunderstorms in the Tennessee Valley are likely to come from warm-season type events. The major events listed in both table 1 and 2 show that the greatest incidence of such storms occurs during the period of June through August. In particular, the more significant small-area storms of Smethport, PA and Holt, MO, occurred in July and June, respectively.

For small-area PMP and TVA precipitation in this report, the three months of June-August represent the all-season maximum. Support for this conclusion is based on the seasonal studies done to develop HMR No. 33 (Riedel et al. 1956) and HMR No. 53 (Ho and Riedel 1980). Both studies apply to small-area PMP, and the storm data mentioned above supports using the same period for TVA precipitation.

2.1.9 Conclusions on PMP-Type Thunderstorms for the Tennessee River Watershed

The discussions in this section suggest the following conclusions:

1. The candidate small-basin type storm for the Tennessee River watershed is of the thunderstorm variety. This storm will most likely occur during the warm season (May-September). However, these storms may occur as early or as late as the so called "transition" months of March-April and/or October-November.

2. In summer, the small-area PMP storm situation will involve a continuation of thunderstorms, fixed geographically, throughout a period lasting up to 24 hr.

3. The summer PMP-type thunderstorm will likely depart from the usual diurnal characteristics of thunderstorms in and near the Tennessee River watershed. The role of diurnal heating will be minimized if the maximum rainfall rates occur during the nighttime hours as in the important Smethport storm.

4. The summer PMP-type thunderstorm will be capable of producing more rainfall in some geographical area (e.g., slopes and valleys in close proximity) than in others (e.g., very flat areas with no nearby slopes).

2.2 Derivation of PMP and TVA Precipitation Values

2.2.1 Introduction

This section discusses the determination of the magnitude of summer PMP and TVA precipitation over small basins. In conforming to the definitions adopted in chapter 1, the rarest known storms with moisture maximization and transposition are guides to defining the PMP level, while the TVA precipitation level is based on storms as observed without moisture maximization and with undercutting of the most extreme events. Maps were derived showing 6-hr 1-mi^2 PMP and TVA precipitation. Depth-area and depth-duration relations were developed for use with these maps to give the extreme precipitation values for other durations up to 24 hr and basin sizes up to 100 mi^2. For the TVA level of precipitation, a family of variable depth-duration curves is provided. An important aspect of the study is the evaluation of topographic factors and their influence on rainfall.

2.2.2 Data

The basic storm information used to determine the short-duration PMP and TVA precipitation are the outstanding storms that occurred in or near the Tennessee River watershed (table 1) and the similar storms which occurred elsewhere in the country (table 2). The most important of the storms outside the Tennessee River watershed was the Smethport, PA storm of July 17-18, 1942.

2.2.3 Topographic Classification

Topography is known to play an important role in rainfall in the Tennessee River watershed. The problem is to develop a meaningful broadscale classification system that can be related to the occurrence of intense storms. One means of assessing topographic factors is from inspection of topographic maps. The Tennessee Valley watershed has been completely mapped to a scale of 1/24,000 on 7 1/2 min quadrangles, with 20-ft contours.

From topographic map inspection, the decision was made that PMP and TVA precipitation estimates should be developed for three classifications of terrain. These were "smooth," typified by the area around Columbia, TN (fig. 1); "rough," typified by most of the Blue Ridge Province; and "intermediate," for which the area around Knoxville is an example. Each quadrangle map in the Tennessee River watershed was classified "smooth," "intermediate," or "rough," in accordance with the following rules:

"Smooth," if there are few elevation differences of 50 ft in 1/4 mi.

"Intermediate," where elevation differences from 50 to 150 ft within 1/4 mi are frequent.

"Rough," if there are general areas with elevation differences exceeding 150 ft within 1/4 mi.

Single isolated mountains or hills did not warrant a rough classification. In areas of narrowing "V"-shaped valleys, elevation differences of less than 150 ft were given a rough classification, based on the idea that this type of land form favors convergence of the air and lifting. For extensive mountain chains or ridges, the rough classification was extended out 3 mi or so away from the mountain.

Under this classification system all of the eastern mountainous part of the Tennessee River watershed is designated as "rough." For the western part of the watershed the classifications of the individual quadrangle maps were noted on a master map of the basin, and a single map constructed dividing the region into the three topographic classes and smoothing (see fig. 67 and 68).

2.2.4 Orographic Effects in the Eastern Blue Ridge-Appalachian Region

Although the eastern portion of the Tennessee River watershed was classified as "rough," this did not adequately explain the variations in rain potential across the region. In some places mountains extend to 6,000 ft above mean sea level. In other places large valleys are sheltered by mountains. This contrast between high mountains and large sheltered valleys required additional consideration besides "roughness" in order to fully assess the orographic effects on intense summer rains.

As an aid to delineating orographic effects, maps of 2-yr and 100-yr return period daily rains were constructed. This was done using all rainfall stations with 15 or more years of record as of 1973. After some consideration, the following concepts evolved and were adopted:

First upslope: This is defined as a mountain slope facing the lowlands in a direction east through southwest with no intervening mountains between the slope and the Gulf of Mexico or the Atlantic. In general, total summer precipitation on first upslope areas is around twice that of sheltered areas.

Secondary upslope: A secondary upslope is high and steep enough to increase precipitation, but is partially shielded upwind (toward moisture source) by a lower mountain range, with an elevation difference between the crests of at least 1,500 ft. Total summer precipitation on secondary slopes is 30 to 50 percent greater than that of sheltered areas.

Sheltered areas: These are defined as valleys having upwind barriers from southeast through southwest of 2,000-ft elevation above sea level or higher.

Depression: The elevation difference between the crest of a barrier and a point within a sheltered area is the "depression" at that point.

A map showing these orographic categories is shown in figure 14. Some smoothing has been done based on both inspection of topographic maps and rainfall behavior. For example, some portions of the Ocoee Basin, while technically "sheltered" by the above definition, according to the rainfall experience of the area, are effectively "first upslope."

2.2.4.1 Adopted Variation of PMP and TVA Precipitation. The following guides are adopted for orographic influence on PMP and TVA precipitation in the eastern portion of the basin:

> Precipitation increase of 10 percent per 1,000 ft from sea level up to 2,500 ft on first upslopes with no further increase above 2,500 ft.
>
> Precipitation increase of 5 percent per 1,000 ft from sea level to all elevations on, secondary upslopes.
>
> Five percent decrease per 1,000 ft of depression in sheltered areas.

2.2.5 Broadscale Sheltering Effects

In the mountainous east portion of the watershed, inflow directions from the south to southwest will affect moisture as it occurs from the southern to the northern edge of the mountainous east. This depletion of moisture will in turn cause a decrease in rainfall potential south to north and is caused by the sheltering effects of the mountainous east terrain. The amount of decrease and how it was derived is explained further in section 2.2.8 and is shown in figure 18.

Rainfall indices, such as 2-yr 24-hr precipitation (see fig. 59), suggest such a broadscale sheltering effect, increasing northward, as interference to moisture inflow by the mountains increases. The suggested decrease amounts to about 10 percent from the Ocoee Basin northeastward to the South Holston Basin (see fig. 18).

2.2.6 TVA Depth-Duration Curves for 1 mi^2

Following the concept of "TVA precipitation" expressed in the introduction to this report (sect. 1.4), the TVA storm for small basins is based on depth-duration curves of observed extreme point rainfalls. The 19 heaviest rainfalls from the list of Tennessee River watershed storms (table 1) are plotted in figure 15, with the storm identification number. The storm rainfall depths given in table 1 were for the maximum storm area for which data were available. The storm data were analyzed using standard procedures (WMO 1973) to develop 1-mi^2 depths. For those storms where only single station or "point" values were available, these values were considered equivalent to average depths over 1 mi^2. Thus, the depth-duration curves in figure 15 apply to an area of 1 mi^2. Added to the plot are the Simpson, KY storm of July 1939 and the Glenville, WV storm of August, 1943. The topographic classification for each storm site is indicated.

Enveloping depth-duration curves for "rough" topography and "smooth" topography were constructed applying the following concepts and principles.

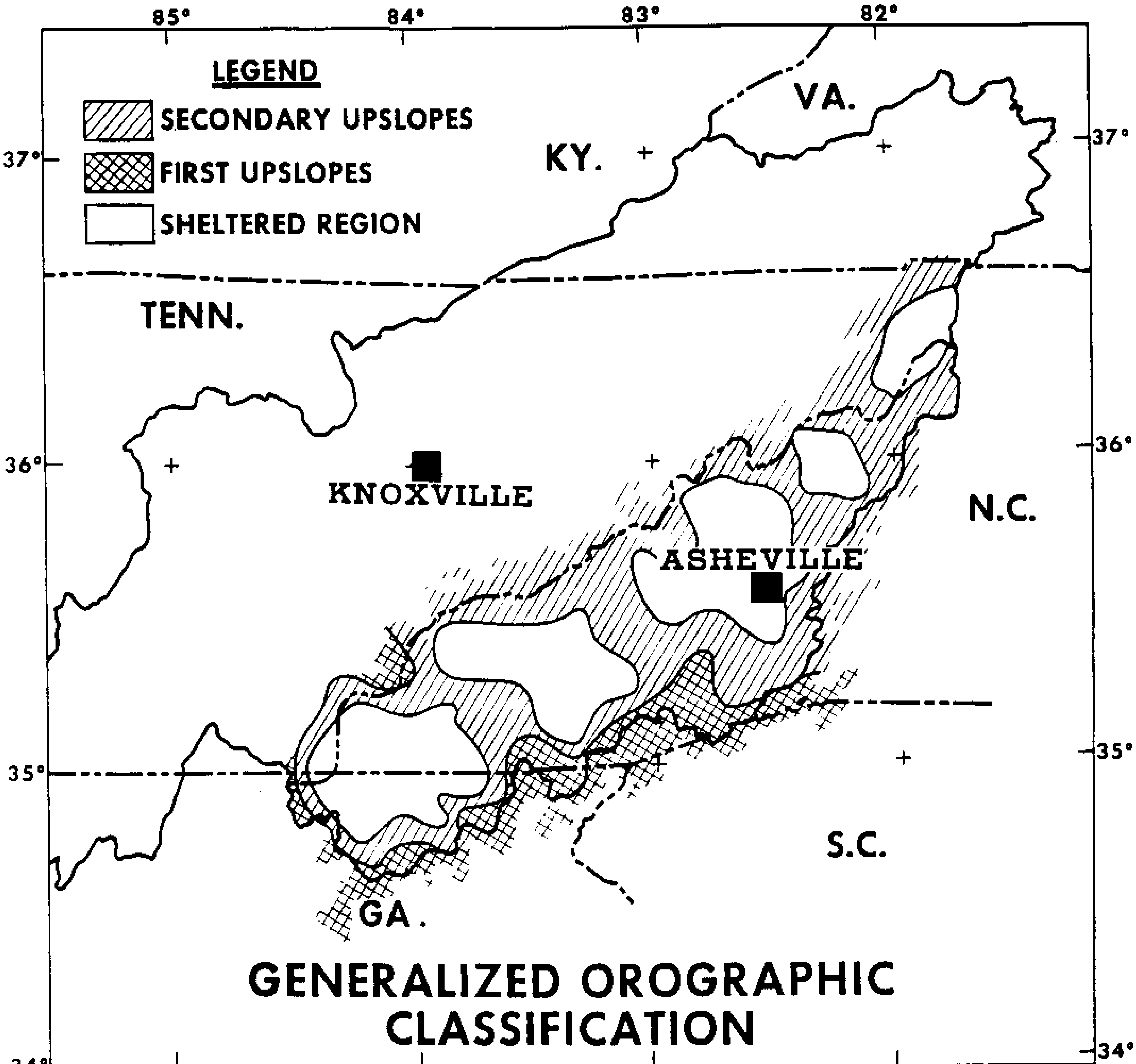


Figure 14--Orographic classifications of the mountainous eastern portion of the Tennessee River watershed.

a. The effect of topography increases in relation to the dynamic effects of the atmosphere during the course of the storm. Since vertical velocities imparted to the air as a result of wind flow against slope remains relatively constant, it plays a less significant role in production of precipitation during the most intense part of the storm than during the remaining time rainfall occurs. Thus, when comparing depth-duration curves over "smooth" and "rough" terrain, a continuous divergence can be expected from hour zero to the total duration of the storm.

b. "Rough" terrain and mountain slopes tend to "fix" the thunderstorm causing the rain to continue over one location for a longer period than over "smooth" terrain where the storm would drift more randomly with the upper level wind, or propogate laterally by its own dynamics. Thus for longer durations, the probability of continued rain after an unusual thunderstorm is enhanced by favorable topography.

c. The TVA-level extreme precipitation corresponds to the largest values that have been observed in the region (without moisture maximization), except that spectacular events that are extreme "outliers" have been undercut. Of the data plotted in figure 15, only the value for Simpson storm falls in this latter category and is undercut. The Simpson storm is considered transposable to some portions of the Tennessee River watershed. The curve for "rough" is drawn through the middle of the range of values (table 1) for storm 37 and envelopes the other storms that have occurred over "rough" terrain in Tennessee. The "smooth" depth-duration curve is drawn through storm number 7 at 3/4 hr.

d. Examination of storms in the Tennessee Valley and surrounding regions indicated a ratio of 0.67 between 1- and 3-hr amounts and 0.80 between 3- and 6-hr amounts would be characteristic of the type of storm capable of producing TVA precipitation. These ratios were used to extend the smooth curve beyond the value indicated by storm number 7. Both depth-duration curves were extended from 6 to 24 hr (dashed) using the relation shown in figure 17 (sect. 2.2.7.2).

To determine the intermediate depth-duration relation for TVA precipitation, simply average the rough and smooth relations given in figure 15.

2.2.7 PMP Depth-Duration Curves for 1 mi^2

Prior to the preparation of HMR No. 45, Hydrometeorological Reports did not distinguish between point rainfalls and average depths over 10 mi^2. Values determined for the 10-mi^2 area were treated as equivalent to point values. When HMR No. 45 was prepared, it was felt that greater refinement was needed, and data would permit PMP estimates for smaller areas to be developed. Consequently, storm data was used in HMR No. 45 to develop depth-duration curves and depth-area-relations that were applicable to a 5-mi^2 area (see, for example fig. 2-15 and 2-23 of HMR No. 45). In HMR No. 51, it was recognized the PMP

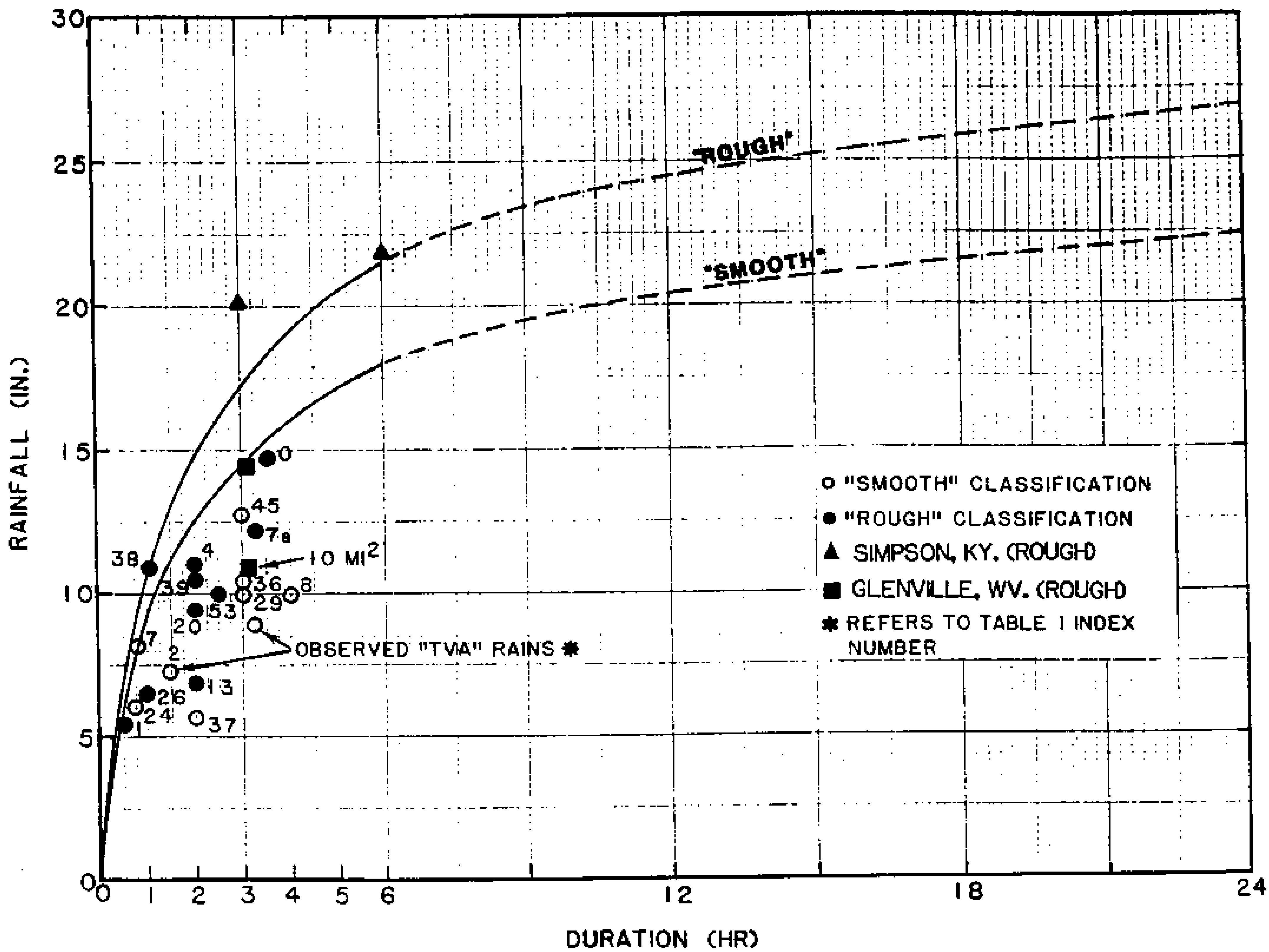


Figure 15.--Adopted 1-mi² TVA precipitation depth-duration curves with supporting data.

estimates for areas less than 10 mi² would be larger than the values shown on the generalized charts. In development of HMR No. 52, 1-hr PMP values were determined for 1 mi². Therefore, it was considered desirable to develop depth-duration relations in the present study, based on the use of 1-mi² (point) storm data. In order to derive these 1-mi² estimates, the transposition and moisture maximization method as described in HMR No. 45 and 51 was used.

2.2.7.1 Development of Curves for Durations of 6 hr and Less. From table 2, storms were selected and maximized, transposed and enveloped to obtain depth-duration curves for rough and smooth terrain. Two storms from this selection were particularly significant in defining the shape of these curves; the Smethport, PA storm of July 17-18, 1942, representing the "rough" category, and the Holt, MO storm of June 22-23, 1947, representing the "smooth" curve. The following considerations were involved in developing the depth-duration envelopes for durations up to 6 hr (solid lines) shown in figure 16.

a. Smethport storm adjustment factors were computed for maximum moisture (using a maximum persisting 12-hr 1000-mb dew point of 76°F and representative persisting 12-hr storm dew point of 74°F) and transposition (using a transposed maximum persisting

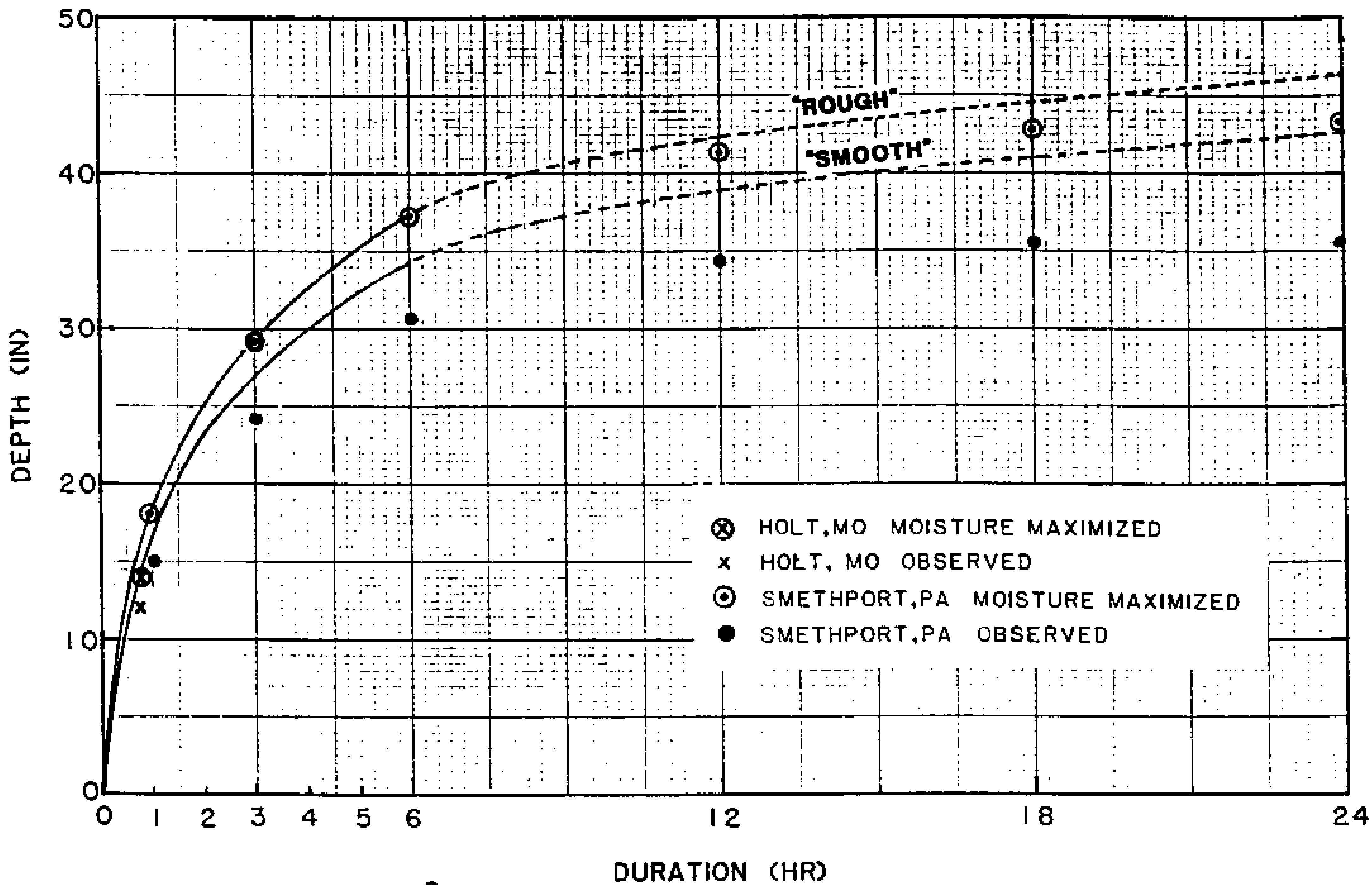


Figure 16.--Adopted 1-mi^2 PMP with supporting data.

12-hr dew point of 78°F). This resulted in a combined adjustment factor of 1.22, which was used to adjust the 1-mi^2 observed storm values of 15.0, 23.0, and 30.7 in. at 1, 3, and 6 hr, respectively. The 1-hr value was determined in the preparation of HMR No. 52 and is discussed in that report. The 3-hr and 6-hr values were obtained from maximum station data relations from analyses in Storm Rainfall in the United States (U.S. Army Corps of Engineers 1945-), rather than the amount at 4.5 hr that was used in figure 2.15 of HMR No. 45. This change from use of the 4.5 hr duration to 1, 3 and 6 hr was made to make intercomparisons consistent between this report and other reports in the HMR series and has no effect on the results. Values from other storms in table 1 or 2 moisture maximized to a persisting 12-hr 1000-mb dew point of 78°F did not exceed those for Smethport. Because the site of the Smethport storm is classified as "rough" under the topography classification system described in section 2.2.3, the enveloping curve in figure 16 is considered applicable to "rough" sites in the Tennessee River watershed.

b. The short duration Holt, MO storm amount of 12.0 in. in 42 min was moisture maximized and transposed, using a maximum dew point of 78°F and a representative persisting 12-hr 1000-mb storm dew point of 75°F, for a combined adjustment factor of 1.20. This is different from the procedure used in

HMR No. 45. In HMR No. 45, the Holt storm was not moisture maximized when transposed to the Tennessee River watershed. The reason for omitting moisture maximization was based on differences found in thunderstorm and tornado frequencies between the midwest and over the Tennessee River watershed. However, recent studies, e.g., Technical Memorandum NWS HYDRO 35 (Frederick et al. 1977), have indicated fewer differences in very short duration precipitation-frequency values between the midwest and Tennessee River watershed. Also, in the development of HMR No. 51, studies indicated the Holt storm should be moisture maximized when it was transposed to the western part of the valley. Therefore, the Holt storm is moisture maximized in this report also. In figure 16, the "smooth" curve envelopes the moisture maximized Holt storm at 42 min (the duration of most intense precipitation).

c. The "rough" depth-duration curve to 6 hr in figure 16 was developed by envelopment of the moisture-maximized, transposed Smethport values. Similar extremes for durations to 6 hr were not found for storms over "smooth" terrain. It was necessary, therefore, to extend the "smooth" curve beyond 1 hr by indirect methods. In the absence of other information, the same 6- to 1-hr ratio was used for both the rough and smooth curves. This resulted in a 6-hr "smooth" value of 34.4 in.

d. Although the topographic classification described in section 2.2.3 defines rough, smooth and intermediate terrain, none of the storms in our sample that occurred over terrain classified as intermediate are significant enough when maximized and transposed to represent this depth-duration curve. This curve is established as a simple average of the "rough" and "smooth" curves. The intermediate curve is not shown in figure 16, however.

e. In HMR No. 45, the ratio between the 6-hr 5-mi^2 TVA and the respective 6-hr 5-mi^2 PMP depth-duration curves was 0.60 for all terrain classes. Comparing figures 15 and 16, these ratios are now 0.58 (rough), 0.55 (intermediate) and 0.53 (smooth) for 6 hr 1 mi^2. These differences are a result of different maximization and envelopment procedures in the development of the TVA and PMP depth-duration curves between the original HMR No. 45 and the current version. Note that, as explained in section 2.2.7.2 below, the ratios 0.58, 0.55, and 0.53 have been extended through 24 hr and are assumed to be valid through 72 hr. The need for durations between 24 and 72 hr will be important in the large basin procedure (see sect. 5.3) when converting the computed PMP to a TVA precipitation for any basin where the majority of the basin is composed of "rough," "intermediate," or "smooth" terrain.

2.2.7.2 Extension of Depth-Duration Curves Through 24 hr. When extending PMP depth-duration curves to longer durations, it is customary to use as a guide the ratio of longer duration to shorter duration precipitation observed in large storms (e.g., HMR No. 41, page 82, Schwarz 1965, and HMR No. 45, page 45, Schwarz and Helfert 1969). Basic information and features of storms appropriate for this purpose in the Tennessee Valley are:

1. 1-mi^2 data available

2. non-tropical

3. of the thunderstorm variety, i.e., exhibiting a "spike" in the storm's rainfall vs. time curve

4. occurs east of the Rocky Mountains; and

5. occurs during the months of April-September when severe thunderstorm activity is most likely.

The storms listed in table 5 with durations equal to or longer than 12 hr were used in development of the extended depth-duration curve. All storms were used in preparing the depth-area curves discussed in section 2.2.10.

The plotted ratios and the adopted durational curve (solid line) are shown in figure 17. The adopted curve resembles the dashed curve drawn through the mean ratio for 12, 18 and 24 hr. The positive deviation of the adopted curve at 24 hr takes into account the fact that with the PMP storm there is most likely to be a continuation of precipitation at the same location to a greater extent than found in most observed storms (sect. 2.1.1). The adopted depth ratio at 24 hr, 1.24, is .03 larger than the mean ratio of 1.21. The adopted depth-duration curve is drawn through the mean depth ratio at 18 hr and somewhat undercuts the ratio at 12 hr. This curve is viewed to be a "best fit" for data from all durations in this region. The list of storms in table 5 includes storms which occur in both "smooth" terrain (e.g., the Keene, OH storm of August 6-7, 1935) and in "rough" terrain (e.g. the Simpson, KY storm of July 4-5, 1939). Consequently, the adopted relationship in figure 17 applies to the "rough" and "smooth" curves of figures 15 and 16 and to the respective intermediate relations.

The adopted curve of figure 17 together with the 6-hr amounts from figure 16 are used to extend the PMP depth-duration curves to 24 hr in figure 16 (dashed lines). To obtain, for example, the 12-hr 1-mi^2 "rough" ("smooth") PMP value, multiply the adopted 12- to 6-hr 1-mi^2 ratio of 1.13 by the 6-hr 1-mi^2 "rough" ("smooth") value of 37.4 (34.4) and obtain the 12-hr 1-mi^2 "rough" ("smooth") PMP value of 42.3 (38.9) in. These values and similar values for the 18- and 24-hr duration were computed and the extended curves are shown in figure 16. The 12- and 18-hr maximized and transposed Smethport values are also shown on this figure for comparison and support of the adopted curve.

Table 6 lists 1-mi^2 PMP and TVA precipitation values for each of the 3 categories (rough, intermediate, and smooth) for 5-min increments up to 1 hr and for each hour to 24 hr. These values were obtained from figures 15 and 16 and are given to aid interpolation of short duration values by the user.

2.2.8 Adjustment for Moisture Gradient and Latitudinal Gradient

The depth-duration curves for 1-mi^2 PMP and TVA precipitation developed in figures 15 and 16 represent the optimum moisture conditions entering the TVA watershed. A geographic variation over the Tennessee River watershed was based

Table 5.--The storms used to develop PMP depth-duration and depth-area curves for the Tennessee River watershed.

Storm Number	Location	Date	6-hr 1-mi^2 Precipitation (in.)	Storm Duration (hr.)
1	Thrall, TX	9/8-10/21	23.4	24
2	Cheyenne, OK	4/3-4/34	20.0	18
3	Woodward Ranch, TX	5/31/35	-	10
4	Keene, OH	8/6-7/35	11.3	24
5	Simpson, KY	7/4-5/39	21.8	12
6	Baldwin, ME*	8/21/39	-	3
7	Hallett, OK	9/5-6/40	18.9	24
8	Plainville, IL*	5/22/41	-	2
9	Smethport, PA	7/17-18/42	30.7	24
10	Larchmont, NY	7/26-28/42	6.21	24
11	Iowa City, IA	9/8/42	6.0	6
12	Gering, NB	6/17-18/43	10.0	10
13	Glenville, WV	8/4-5/43	14.9	9
14	Stanton, NB	6/12-13/44	15.5	24
15	Jerome, IA	7/16-17/46	8.7	24
16	Holt, MO	6/22-23/47	12.2	10
17	Stromburg, NB	6/26-27/48	8.2	18
18	Dumont, IA	6/25/51	9.4	12
19	Clear Spring, MD	7/22-23/53	11.0	18

*Not considered in figure 17

on a moisture or rainfall gradient. The "latitudinal gradient chart" for the mountainous east was developed as shown in figure 18. The latitudinal gradient chart, based on observed rainfall gradients due primarily to sheltering by mountains, implicitly incorporates moisture effects.

While observed rainfall gradients satisfactorily defined the variation in PMP estimates in the mountainous east, an assessment of moisture parameters was required to adequately define the PMP gradient over the remainder of the basin. The moisture adjustment charts (fig. 19 and 20) were made from an assessment of mean and extreme dew points. Dodd's charts (1965) provided the information on mean dew points, while maximum persisting 12-hr dew points developed in the Hydrometeorological Branch (Environmental Data Service, 1968) provided the source of maximum dew points. These dew point sources were supplemented by a survey of high dew point situations affecting the Tennessee area during the period of 1956-1965. From several situations, an outstanding period from July 26, 1956 to August 6, 1956, was selected for analysis. Mean dew points for stations in and around Tennessee were averaged for this period. The result is shown in figure 21. All station dew points were reduced moist-adiabatically to 1000 mb before being plotted and analyzed. This 12-day period consisted of recurring high dew points and is considered representative of a persisting high dew point situation that precedes and accompanies extreme summer rainfall occurrence. No evidence has been found in recent dew point data that this situation has since been exceeded.

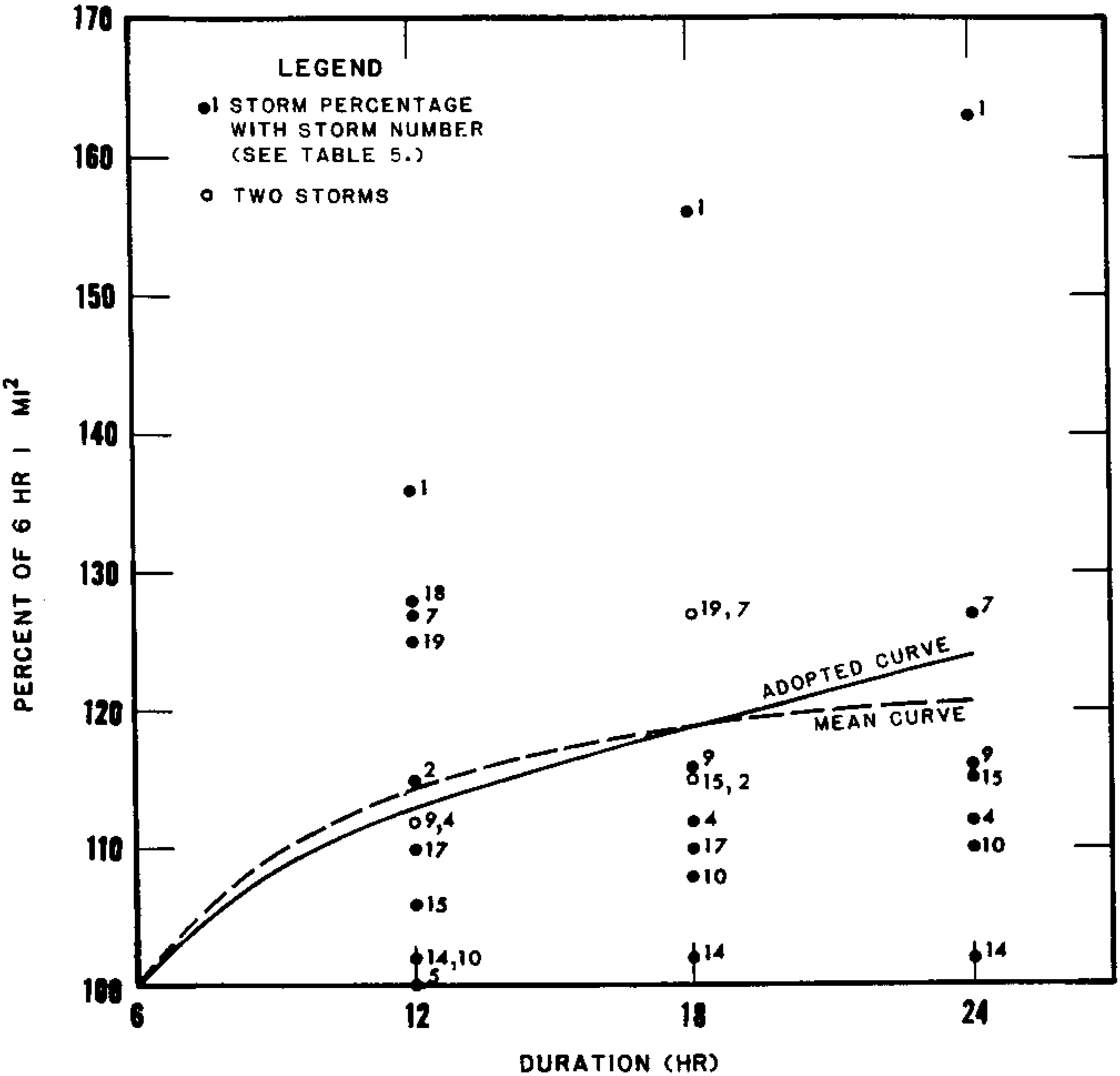


Figure 17.--Adopted small basin PMP depth-duration curve with supporting data.

The various analyses support a regional dew point gradient of about 2°F from the southwestern to the northeastern portion of the basin. This corresponds to a difference in rainfall of 10 percent, based on the usual model for convective rain during extreme storms (U.S. Weather Bureau 1947). Figure 19 shows the moisture index lines in percent for the western portion of the basin, while figure 20 covers the nonmountainous eastern part.

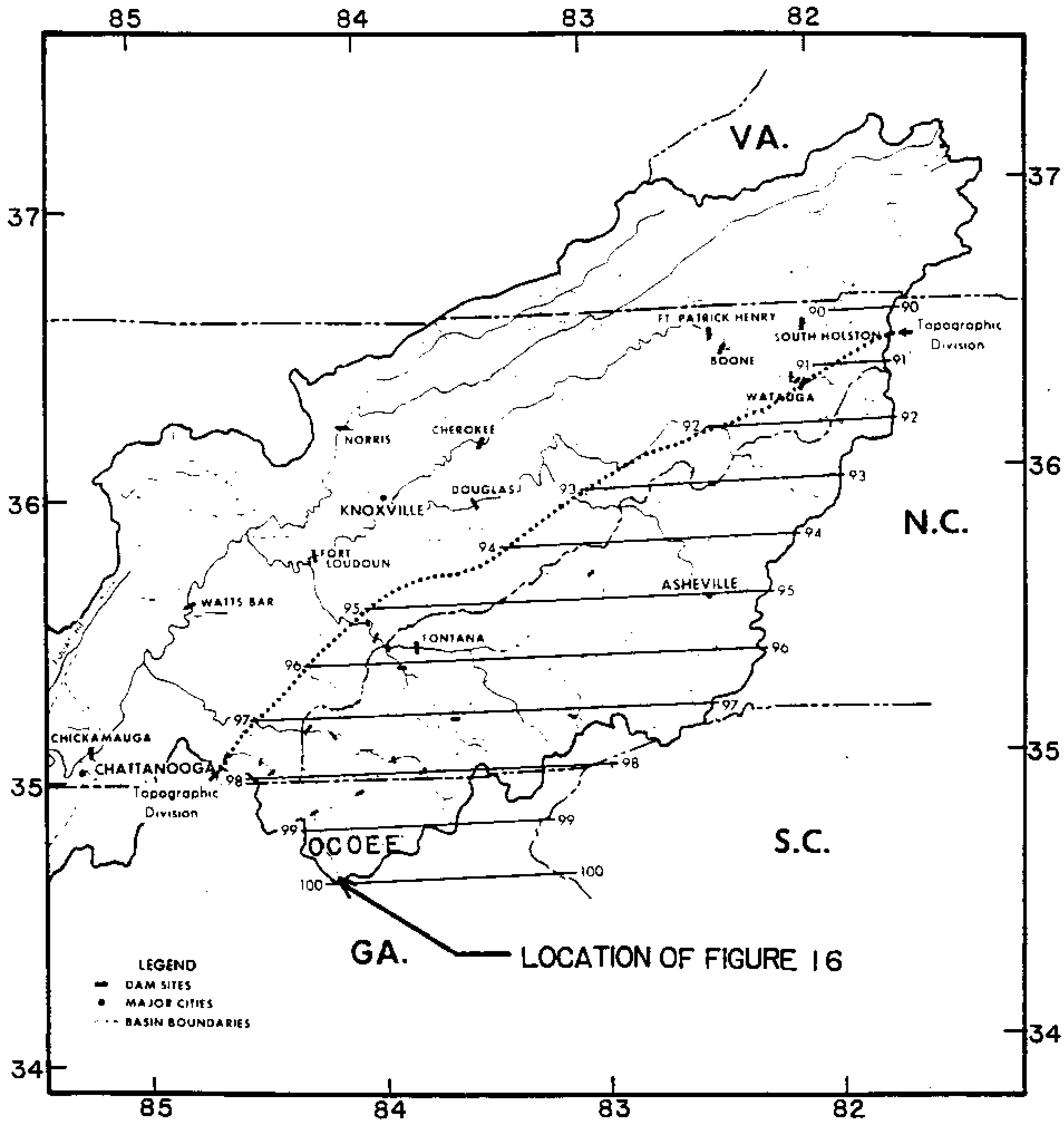
The moisture adjustment percentage lines of figure 20 and the latitudinal gradient percentage lines of figure 18 for the east have similar but not identical values at their boundary, as they derive from different concepts. This

Table 6.—1-mi^2 PMP and TVA precipitation values from 5 min to 24 hr

Duration	PMP (rough)	PMP (int.)	PMP (smooth)	Duration	PMP (rough)	PMP (int.)	PMP (smooth)
5 min.	3.4	3.2	2.9	7 hr	38.8	37.2	35.7
10 min	5.9	5.4	5.0	8 hr	39.8	38.2	36.6
15 min	8.1	7.4	6.8	9 hr	40.7	39.0	37.3
20 min	9.8	9.1	8.4	10 hr	41.3	39.6	37.9
25 min	11.3	10.6	9.8	11 hr	41.8	40.1	38.4
30 min	12.6	11.8	11.1	12 hr	42.3	40.6	38.9
35 min	13.8	13.0	12.3	13 hr	42.8	41.0	39.3
40 min	14.9	14.1	13.3	14 hr	43.2	41.4	39.7
45 min	15.8	15.1	14.3	15 hr	43.6	41.8	40.0
50 min	16.7	16.0	15.2	16 hr	43.9	42.1	40.9
55 min	17.5	16.8	16.0	17 hr	44.2	42.4	40.6
60 min	18.2	17.4	16.7	18 hr	44.5	42.7	40.9
2 hr	25.1	24.2	23.2	19 hr	44.9	43.0	41.2
3 hr	29.2	28.0	26.9	20 hr	45.2	43.3	41.5
4 hr	32.5	31.2	29.9	21 hr	45.5	43.6	41.8
5 hr	35.2	33.8	32.4	22 hr	45.8	43.9	42.1
6 hr	37.4	35.9	34.4	23 hr	46.1	44.2	42.4
				24 hr	46.4	44.5	42.6

Table 6. 1-mi^2 PMP and TVA precipitation values from 5 min to 24 hr (continued).

Duration	TVA (rough)	TVA (int.)	TVA (smooth)	Duration	TVA (rough)	TVA (int.)	TVA (smooth)
5 min	2.0	1.6	1.2	7 hr	22.3	20.5	18.7
10 min	3.6	3.0	2.4	8 hr	22.9	20.0	19.2
15 min	5.0	4.2	3.5	9 hr	23.4	21.4	19.5
20 min	6.0	5.2	4.5	10 hr	23.8	21.8	19.8
25 min	6.8	6.2	5.5	11 hr	24.1	22.1	20.1
30 min	7.5	6.9	6.3	12 hr	24.4	22.4	20.4
35 min	8.2	7.6	7.0	13 hr	24.7	22.6	20.6
40 min	8.9	8.3	7.7	14 hr	24.9	22.8	20.8
45 min	9.5	8.9	8.3	15 hr	25.1	23.0	21.0
50 min	10.0	9.4	8.8	16 hr	25.3	23.2	21.2
55 min	10.5	9.9	9.3	17 hr	25.5	23.4	21.3
60 min	11.0	10.4	9.7	18 hr	25.7	23.6	21.5
2 hr	14.7	13.6	12.5	19 hr	25.9	23.8	21.7
3 hr	17.3	15.9	14.5	20 hr	26.1	24.0	21.8
4 hr	19.2	17.6	16.0	21 hr	26.3	24.2	22.0
5 hr	20.6	18.9	17.2	22 hr	26.5	24.4	22.2
6 hr	21.6	19.8	18.1	23 hr	26.7	24.5	22.3
				24 hr	26.8	24.6	22.4



'igure 18.--Broadscale sheltering (in percent) by mountainous complex of eastern Tennessee River watershed.

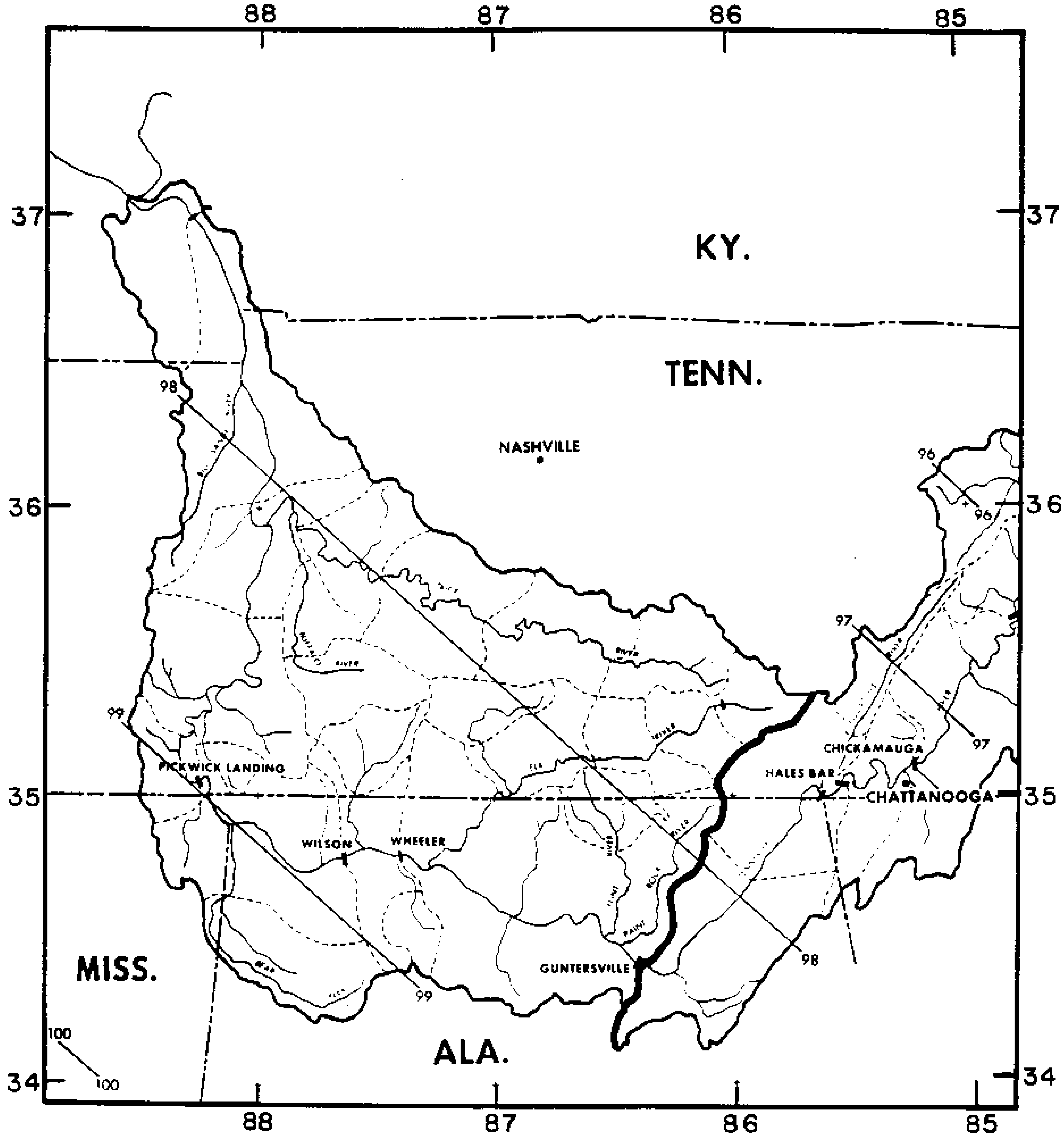


Figure 19.--Moisture index chart (in percent) - western half of Tennessee River watershed (note overlap of eastern region shown in fig. 20).

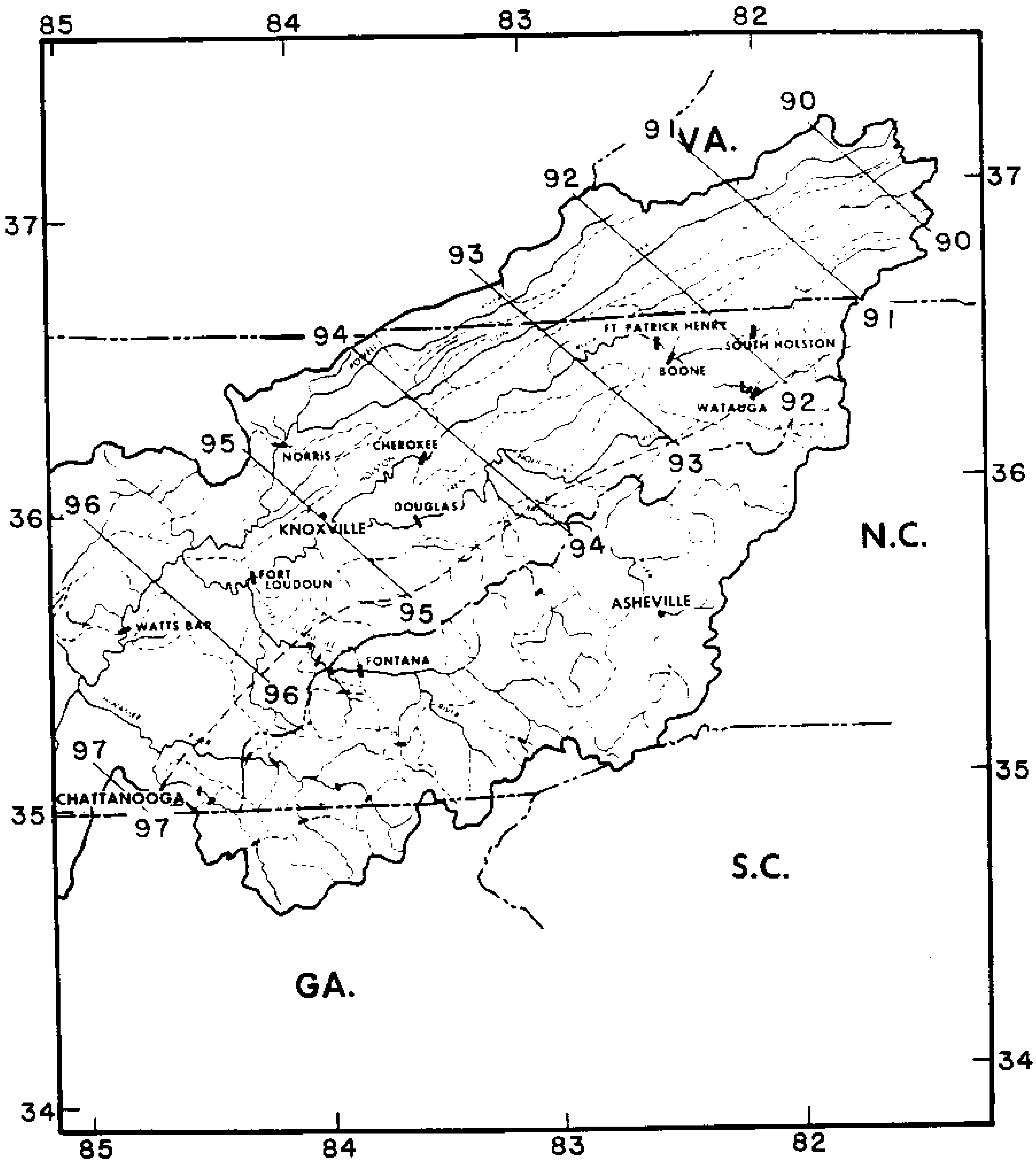


Figure 20.—Moisture index chart (in percent) - eastern half of Tennessee River watershed.

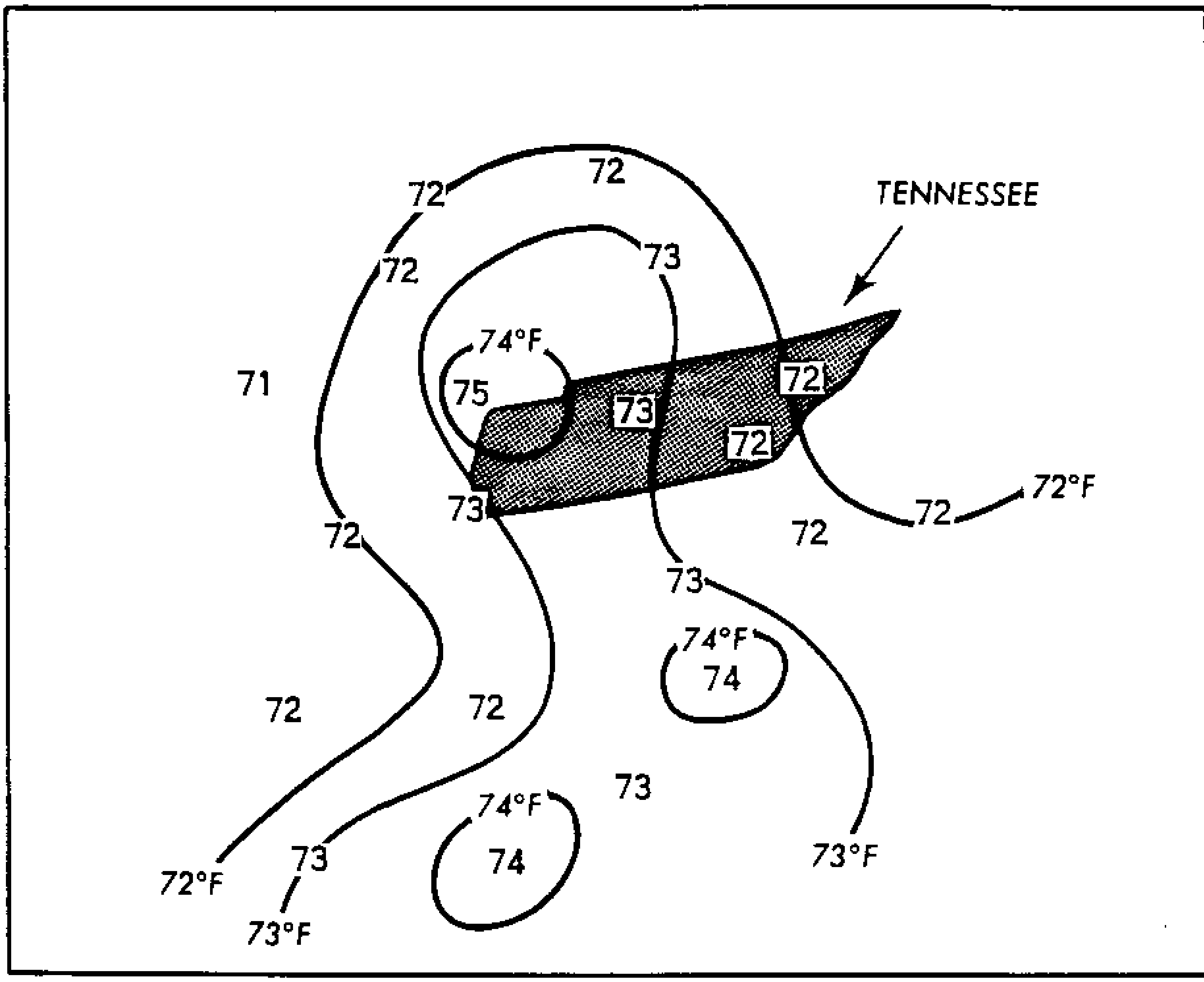


Figure 21.--Mean dew points for high moisture inflow situation of July 25-August 6, 1956.

discontinuity is taken care of by smoothing in the final precipitation index maps, figures 22 to 25. A single percentage map without discontinuities, while esthetically pleasing, would have little additional practical significance and therefore was not constructed.

2.2.9 Precipitation Index Maps for 6 hr 1 mi^2

The charts and concepts discussed previously were used to develop 6-hr 1-mi^2 index maps of PMP (figs. 22 and 23) and TVA precipitation (figs. 24 and 25).

2.2.9.1 Probable Maximum Precipitation. 6-hr 1-mi^2 PMP values from figure 16 of 34.4, 35.9 (by interpolation), and 37.4 in. were assigned to smooth, intermediate and rough terrain categories, respectively, at the southwestern edge of the basin. These were then adjusted over the western and central portion of the basin by multiplying by the moisture adjustment percents of figures 19 and 20. A value was computed for each 7 1/2-min quadrangle (sect. 2.2.3). and multiplied by the moisture adjustment percents of either figure 19 or 20. Isohyets of 6-hr 1-mi^2 PMP were then constructed, placing the steepest gradient in the vicinity of the most important changes in elevation. While these gradients may appear artificial, the approach nevertheless provides a reasonable placement of the maximum gradient, i.e., near the edges of the Cumberland Plateau.

Table 7. Ratios for adjusting 6-hr 1-mi^2 TVA precipitation depths to values for other durations

Duration (hr)	1	2	3	6	12	18	24
Ratio	0.51	0.68	0.80	1.00	1.13	1.19	1.24

In the mountainous east (classified rough), a basic 6-hr "rough" PMP value of 37.4 in. was assigned the southern edge of the basin (i.e., at the point of contact with the 100 percent line of fig. 18). This was progressively reduced to the north by means of the percentage lines of figure 18. The topographic adjustments, such as for the "first upslope" (sect. 2.2.3 and fig. 14) were then applied to the reduced values. With some smoothing the basic PMP index charts, figures 22 and 23, were obtained. Note that in figures 22 and 23 some of the isohyets are labeled in tenths. This is because the orographic adjustments described in detail in sections 3.5.2 and 3.5.3 are computed to the nearest five hundredths (.05). These orographic adjustments are "built into" the 6-hr 1-mi^2 PMP values in figures 22 and 23. Because of the accuracy with which the total orographic adjustments are computed, it is necessary to round the isohyet labels to the nearest tenths.

2.2.9.2 Tennessee Valley Authority Precipitation. The 6-hr 1-mi^2 TVA precipitation index charts, figures 24 and 25, are developed in an identical manner to the PMP index map. The basic values of 18.1, 19.8 and 21.6 in. for 1 mi^2 over "smooth," "intermediate," and "rough" surfaces, respectively, were determined from figure 15. For the mountainous east, the 21.6 in. ("rough" classification) was placed at the 100 percent line of figure 18.

2.2.9.3 Ratios of 6-hr 1-mi^2 TVA Precipitation to Other Durations. The generalized charts of TVA precipitation (see fig. 24 and 25) provide values for the 6-hr duration. To obtain values for other durations, it is necessary to use the relationships given in figure 15 to find ratios to compute values for other durations. For convenience, these ratios are shown in table 7 for the most common durations.

2.2.10 Depth-Area Relations

Basic 1-mi^2 PMP and TVA precipitation are adjusted for size of basin up to 100 mi^2 according to the adopted reduction factors shown in figure 26. To develop the depth-area curves in figure 26, depth-area curves from several important storms outside the Tennessee River watershed were analyzed. These storms are listed in table 5 and their five basic characteristics are mentioned in section 2.2.7.2.

In selecting the particular storms in table 5, the basic premise was that the storm most likely to be the candidate PMP storm for small basins and short durations in the Tennessee River watershed would be a thunderstorm occurring between April and September. All the storms in table 5 are of this type, occurring in regions and terrain similar enough to some portion of the Tennessee River Valley that they could have occurred in a meteorological sense just as easily in the Tennessee River watershed.

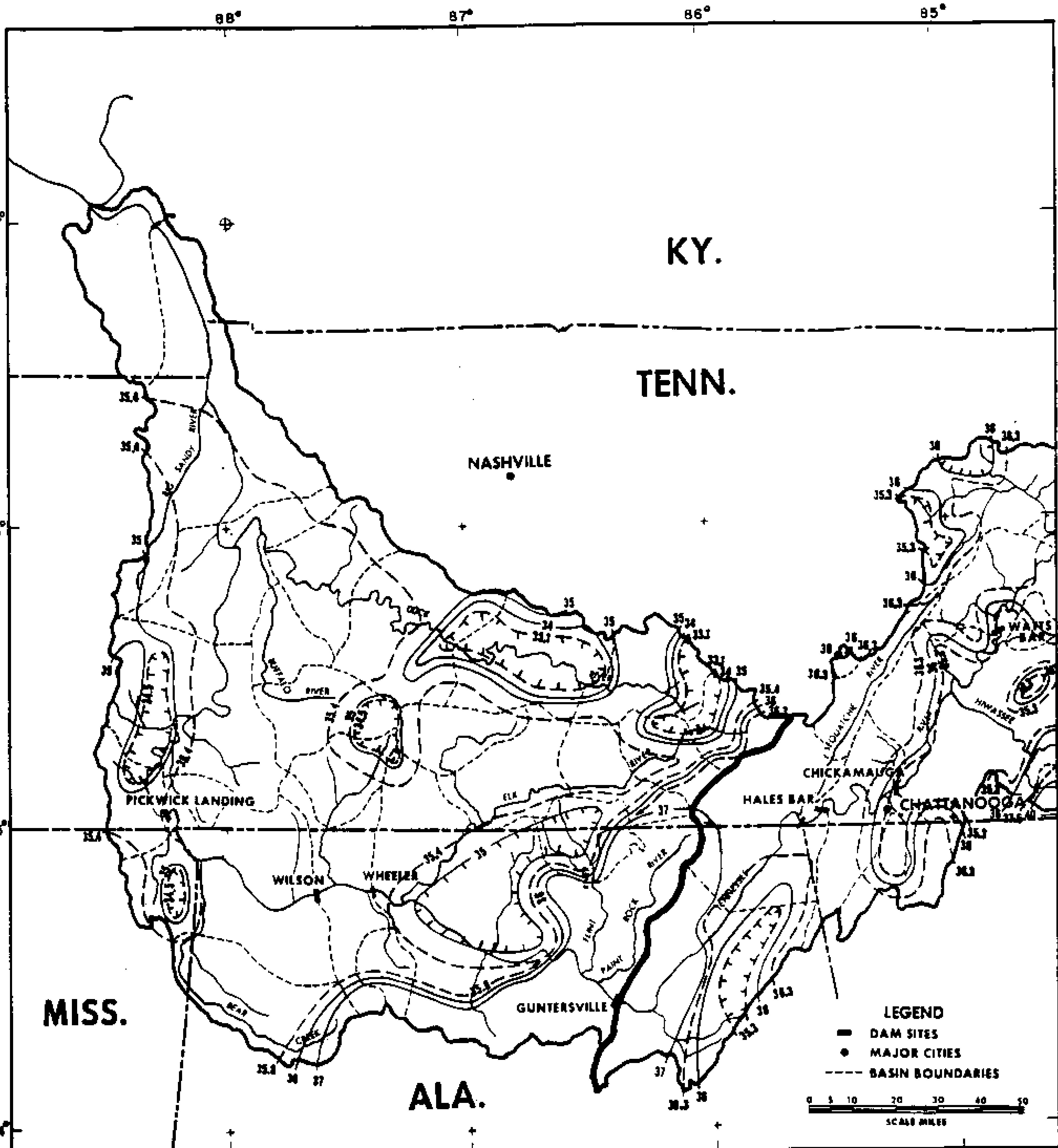


Figure 22.-- 6-hr 1-mi^2 PMP (in.)-western half of Tennessee River watershed (note overlap of eastern region in fig. 23).

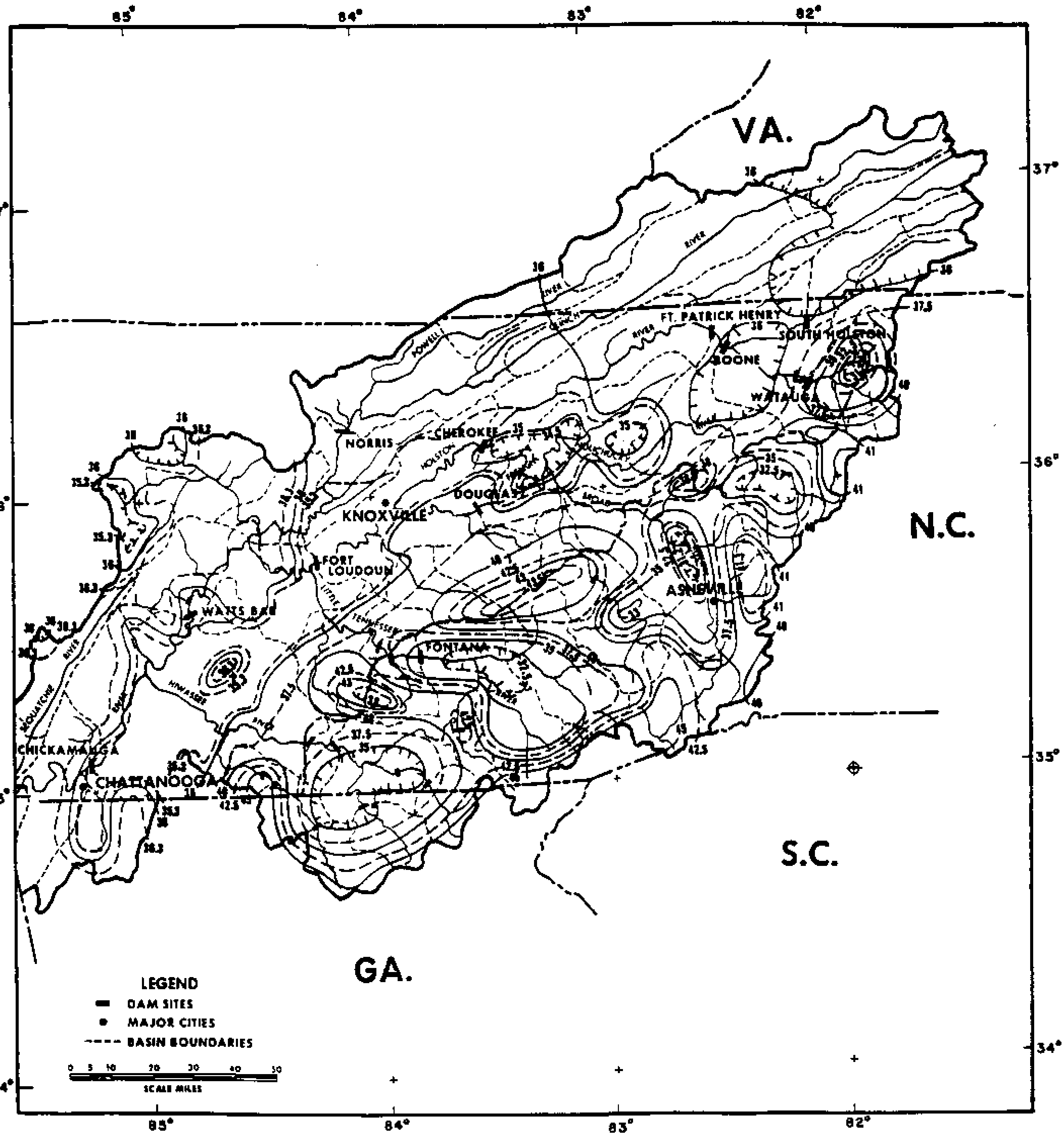


Figure 23.—6-hr 1-mi^2 PMP (in.)—eastern half of Tennessee River watershed.

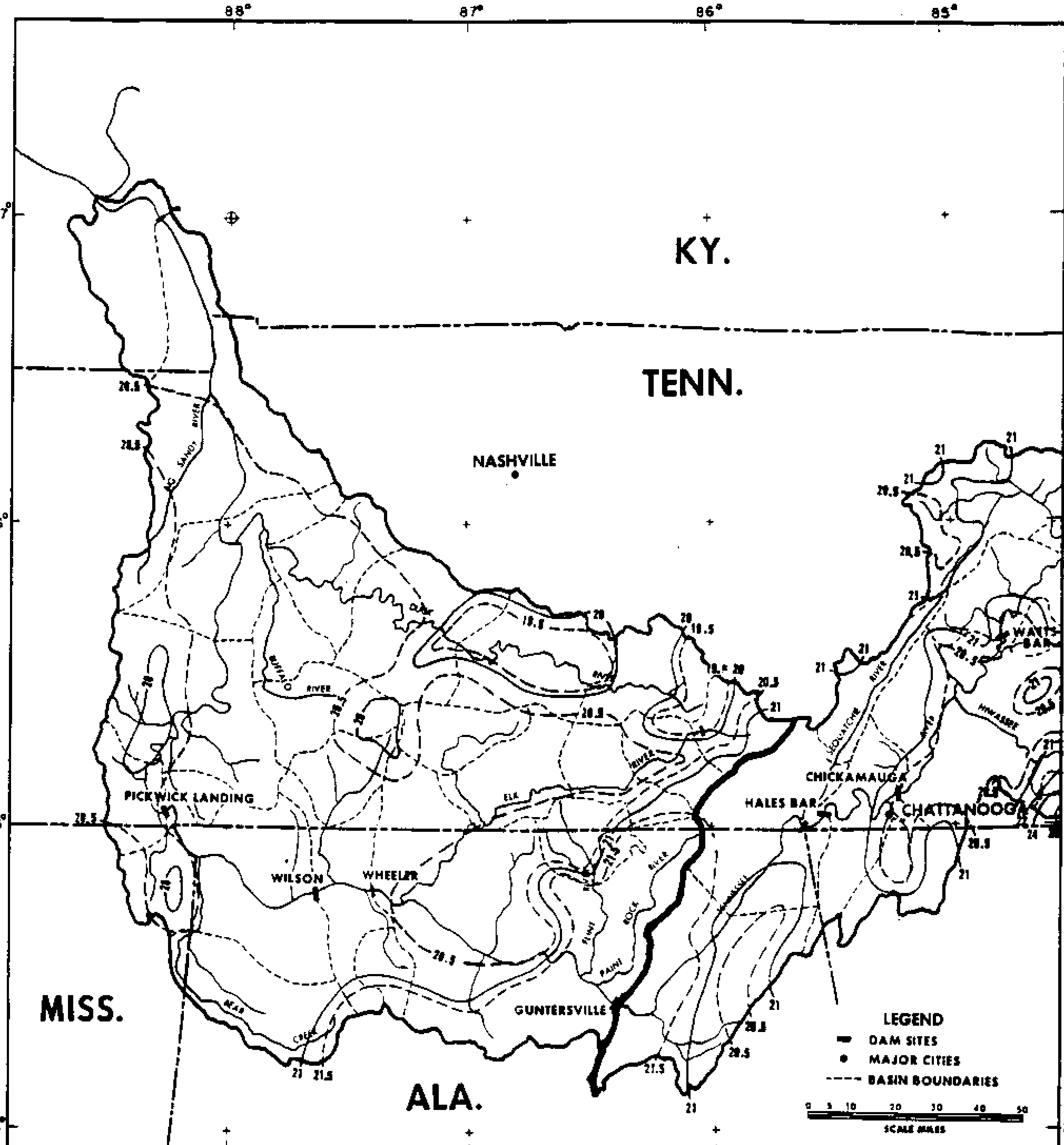


Figure 24.--6-hr 1-mi^2 TVA precipitation (in.)-western half of Tennessee River watershed (note overlap of eastern region in fig. 25).

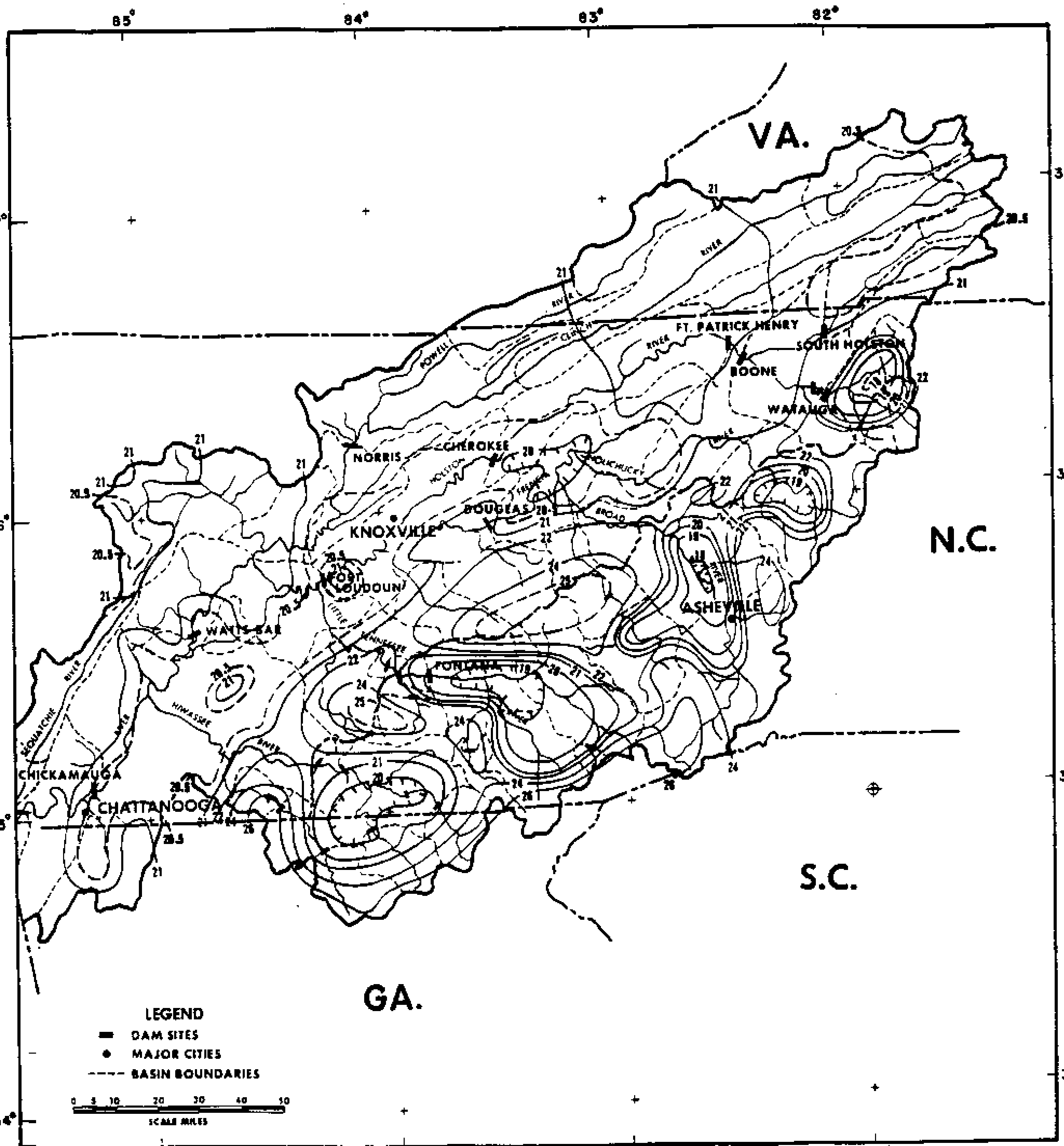


Figure 25.--6-hr 1-mi^2 TVA precipitation (in.)-eastern half of Tennessee River watershed.

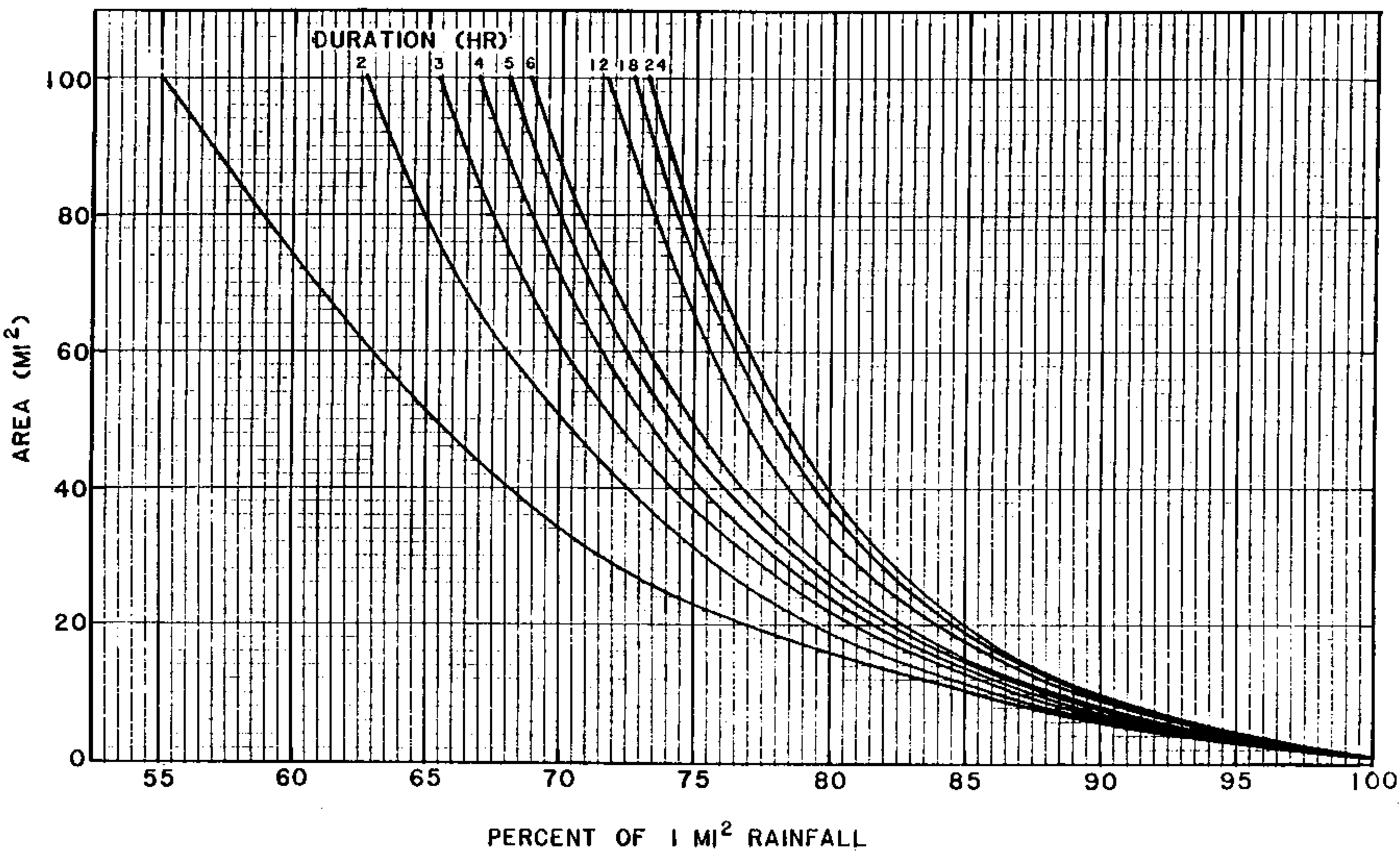


Figure 26.--Depth-area relations for small-basin estimates.

In order to derive the depth-area relations, each storm in table 5 was analyzed for durations of 1, 3, 6 and 24 hr (if data were available at any, or all of these durations). For each duration, area size vs. percentage of 1-mi^2 depth was plotted for each storm. In drawing the final depth-area curves at 1, 3, 6 and 24 hr, an attempt was made to draw as close as possible to the mean percentage of all storms at each duration. It was concluded that sufficient maximization was present in developing the index maps. For the depth-area reduction, therefore, representative curves would be appropriate. However, in order to ensure that the depth-duration, as well as depth-area curves, were both smooth and consistent for area sizes up to 100 mi^2, some adjustments to the depth-area curves for individual durations were necessary. This is illustrated in figure 27 for the 3-hr duration. The adopted curve varies only a few percent from a curve drawn through the mean of the data. Once the curves at 1, 3, 6 and 24 hr were established, depth-duration curves at various area sizes were drawn in order to obtain depth-area curves at the other durations (2, 4, 5, 12 and 18 hr). Data from storms in both "smooth" and "rough" regions were included in the development of the depth-area curves. Therefore, the adopted curves apply to both "rough" and "smooth" depth-duration relations. In addition, the adopted curves apply to both PMP and TVA precipitation, even though no storms from the Tennessee River watershed (table 1) were used in the depth-area analysis. This is because few, if any, Tennessee River watershed storms exceeded 6 hr in duration.

Figures 28 and 29 show the depth-area curves for some of the more significant storms of table 1 compared to the adopted curve for a duration of 3 hr. The approximate duration of the rainfall is indicated in the parentheses for each storm shown.

Figure 30 shows the adopted 3-hr depth-area curve along with similar curves from a few of the more significant storms outside the basin, including the Smethport storm. The adopted 3-hr curve from HMR No. 39 (Schwarz 1963) is also shown, since this was derived from a somewhat similar assessment of outstanding thunderstorm occurrences.

2.2.11 Variable Depth-Duration Criteria for TVA Precipitation, Index Value 19.8 in.

Storm events show considerably different depth-duration characteristics. In observed general storms, the ratio of 24-hr to 6-hr precipitation varies with the critical length of the storm. Such observed relations are preserved in the TVA precipitation criteria. It is desired to obtain a depth-duration curve characteristic of a storm of given duration. Thus, if for a particular basin a 12-hr total storm period is critical, the 3-hr rain to be used is not the extreme 3-hr rain, but rather a maximum 3-hr rainfall increment that is characteristic of a 12-hr storm.

Depth-duration data for 3-, 6-, 12- and 24-hr storms were compiled from Storm Rainfall in the United States (U.S. Army 1945 -) and other sources (Hershfield 1961 and U.S. Weather Bureau 1966). Figure 31 shows adopted TVA precipitation depth-duration curves based on these data for storm durations of 3 to 24 hr. Any of these curves applies directly to any basin where the 6-hr 1-mi^2 TVA precipitation is 19.8 in. (fig. 24 and 25 "intermediate" classification). Treatment of the full range of index values is covered in section 2.2.12.

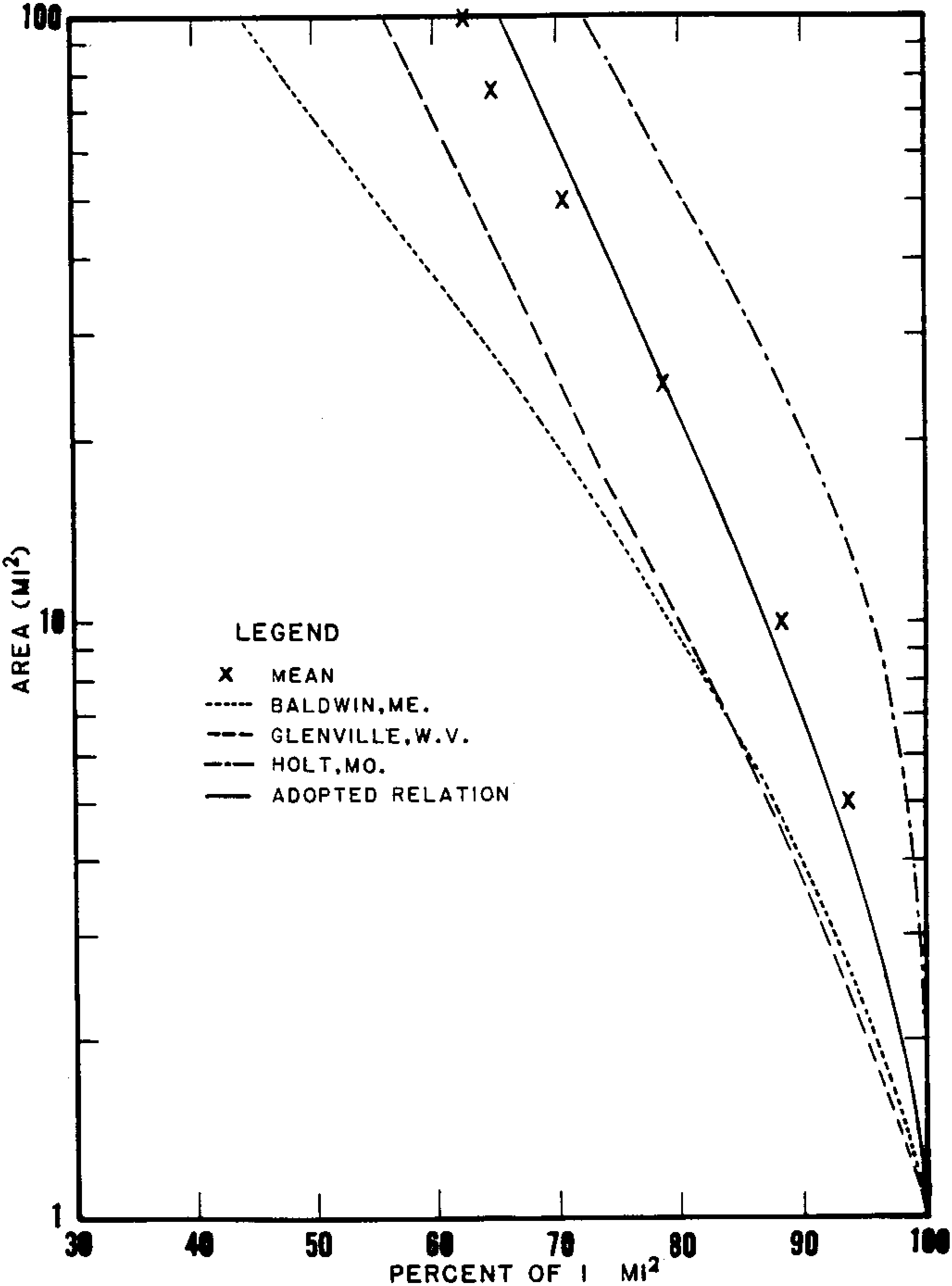


Figure 27.--Depth-area relations for 3 hr with data from other storms.

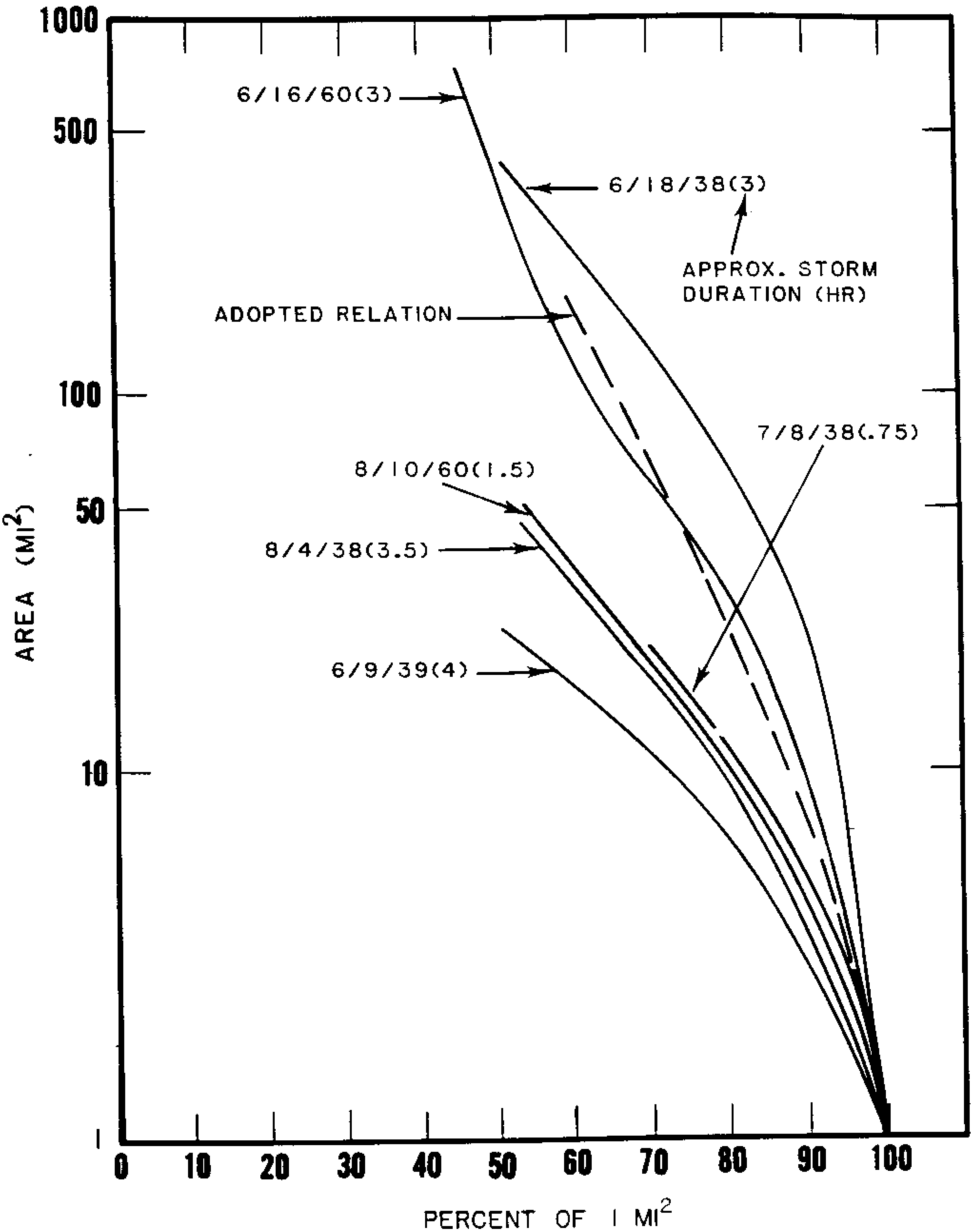


Figure 28.--Adopted 3-hr depth-area curve compared with Tennessee River watershed intense storm data.

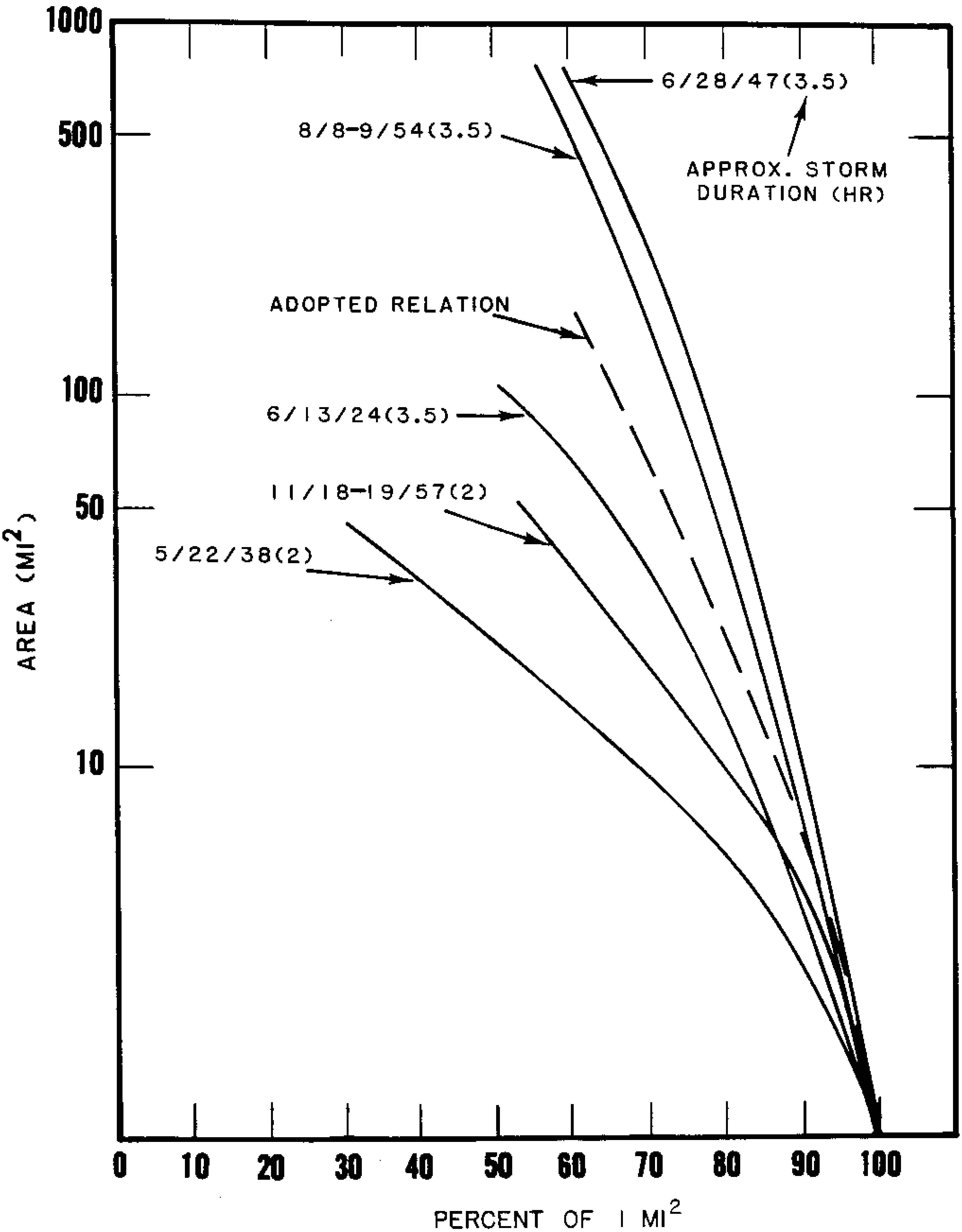


Figure 29.--Adopted 3-hr depth-area curve compared with Tennessee River watershed intense storm data.

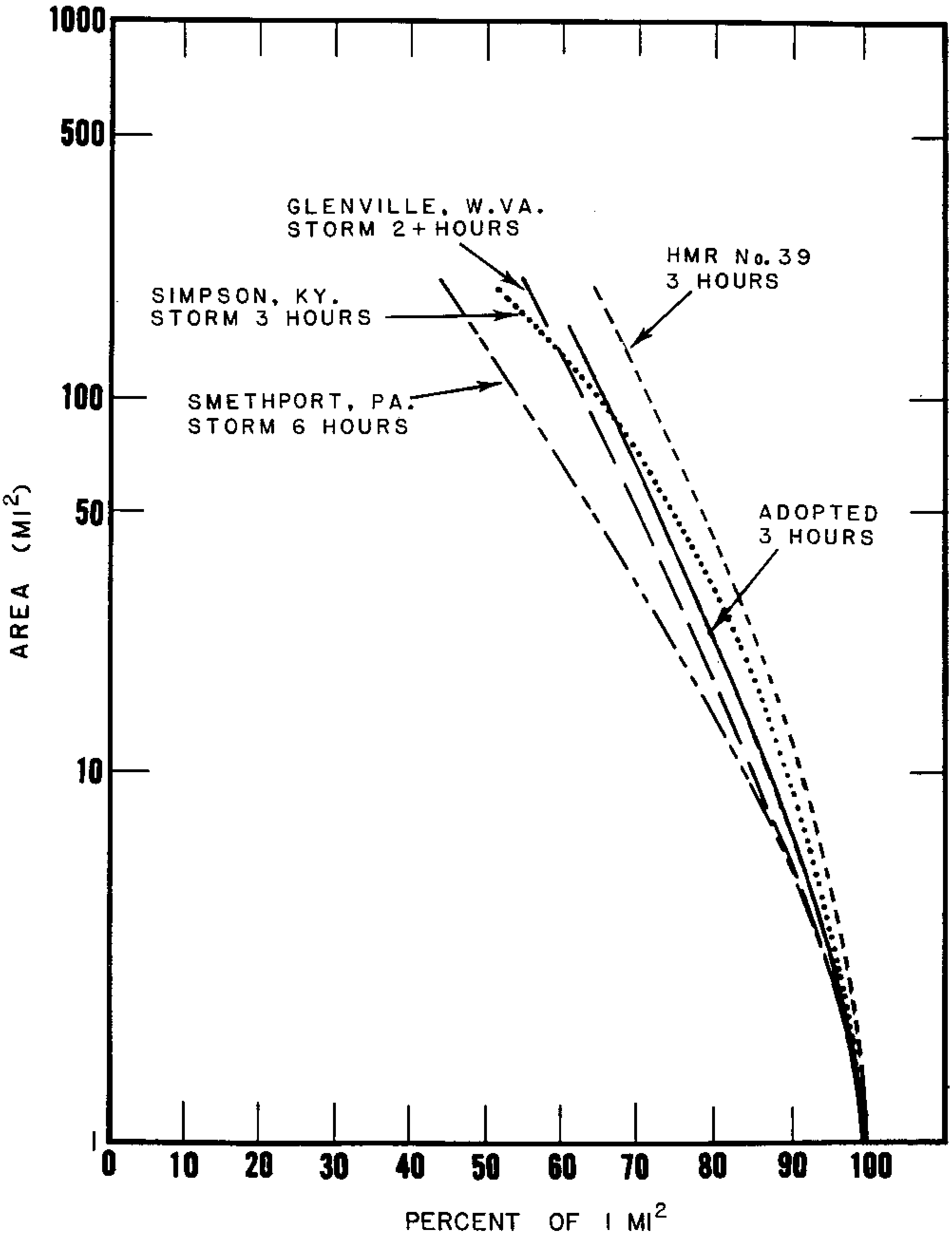


Figure 30.--Adopted 3-hr depth-area curve compared with data from storms outside the basin.

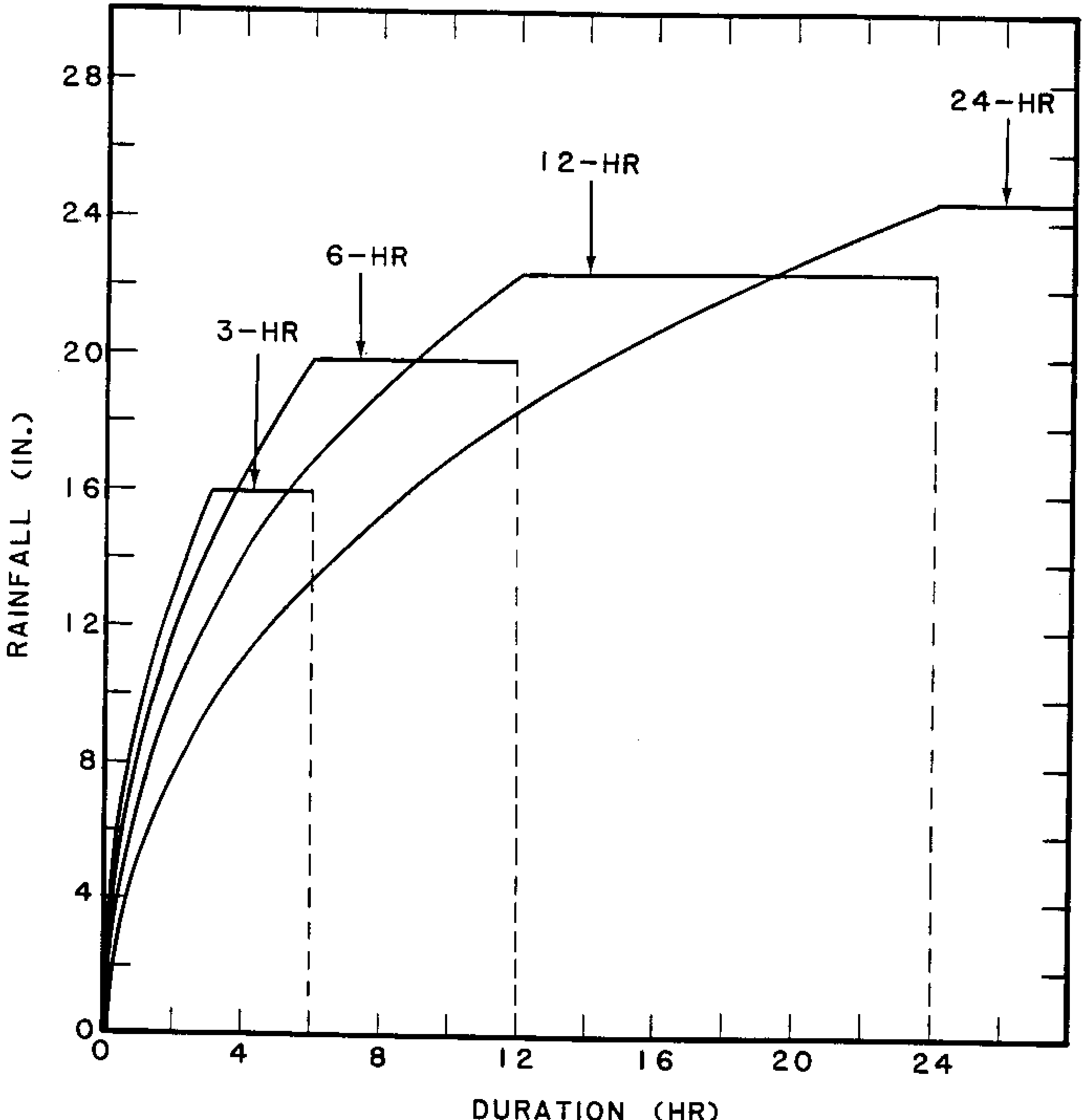


Figure 31.--Adopted depth-duration curves for 3-, 6-, 12- and 24-hr TVA storm ("intermediate" classification).

The appropriate TVA precipitation depth-duration curve for a particular basin is the one that leads to most critical discharge as determined by hydrologic trial. The short-duration curves provide higher peak intensities, whereas the longer duration curves provide larger total volume. It is valid to interpolate between the curves for intermediate storm durations. The curves indicate no rain for 3 hr after the 3-hr storm, no rain for 6 hr after the 6-hr storm, etc. Depth-duration values are undefined beyond the indicated durations. Figures 32 to 34 repeat the depth-duration curves with some of the supporting data from storms listed in table 5.

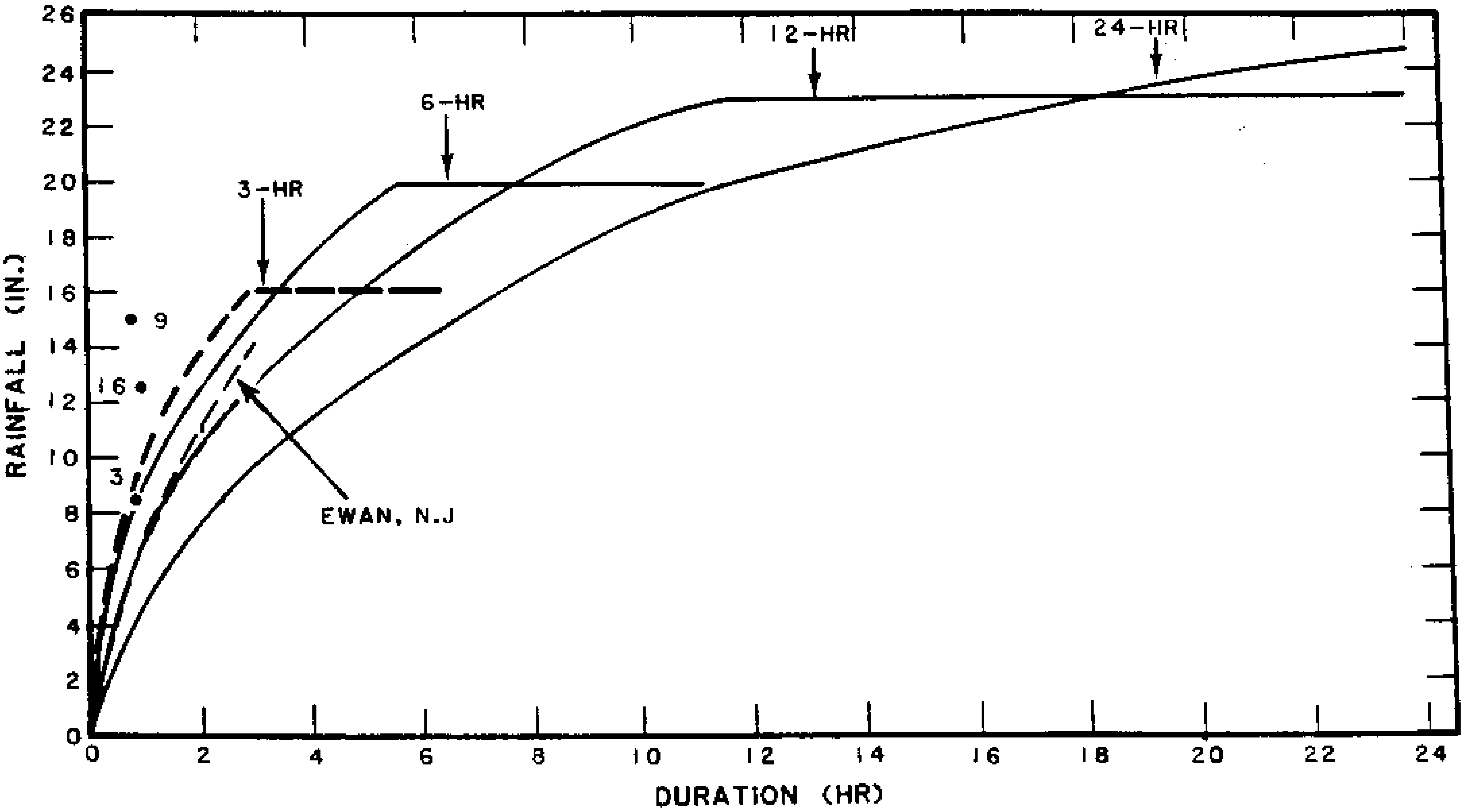


Figure 32.—Curves of figure 31 with supporting data for 3 hr.

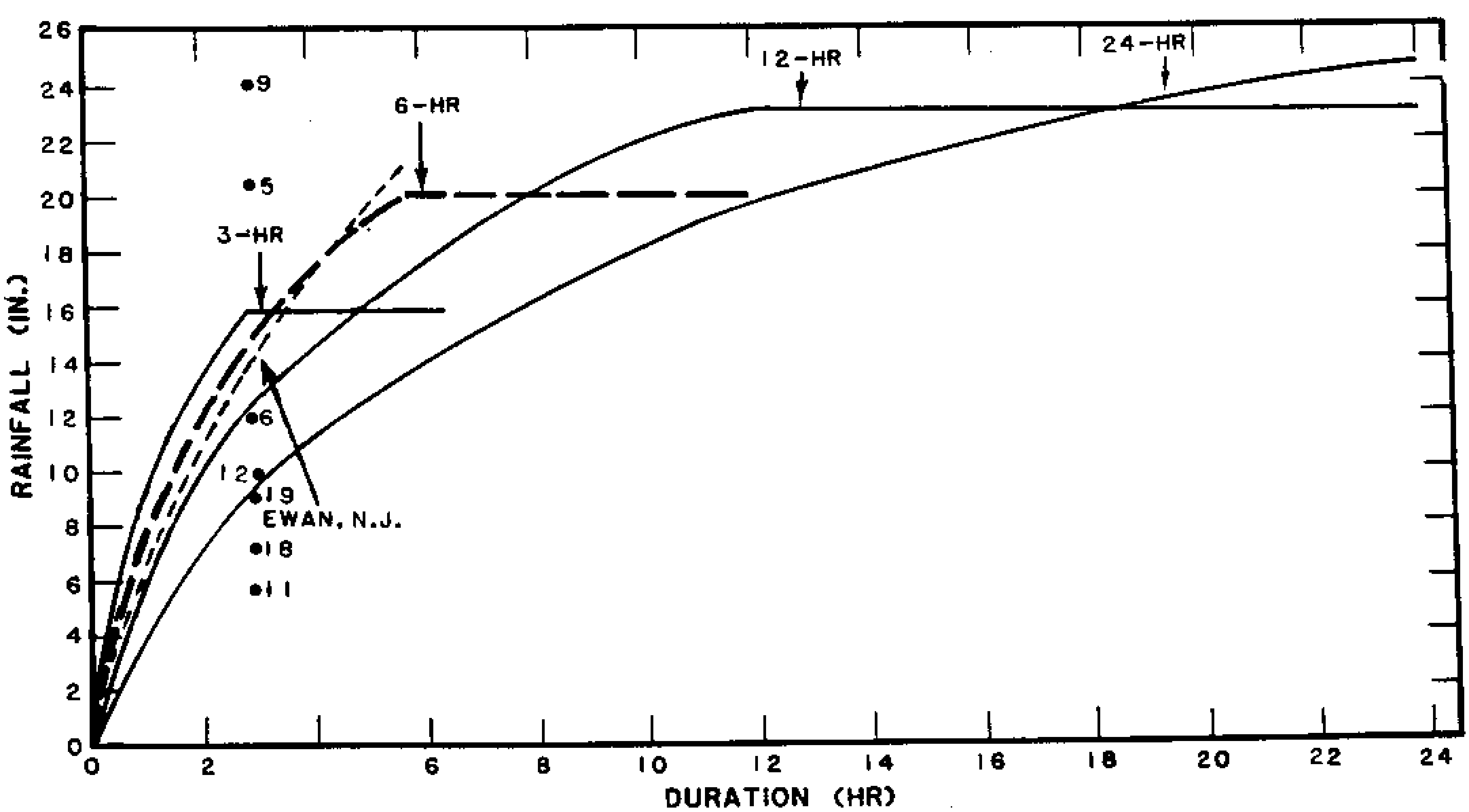


Figure 33.—Curves of figure 31 with supporting data for 6 hr.

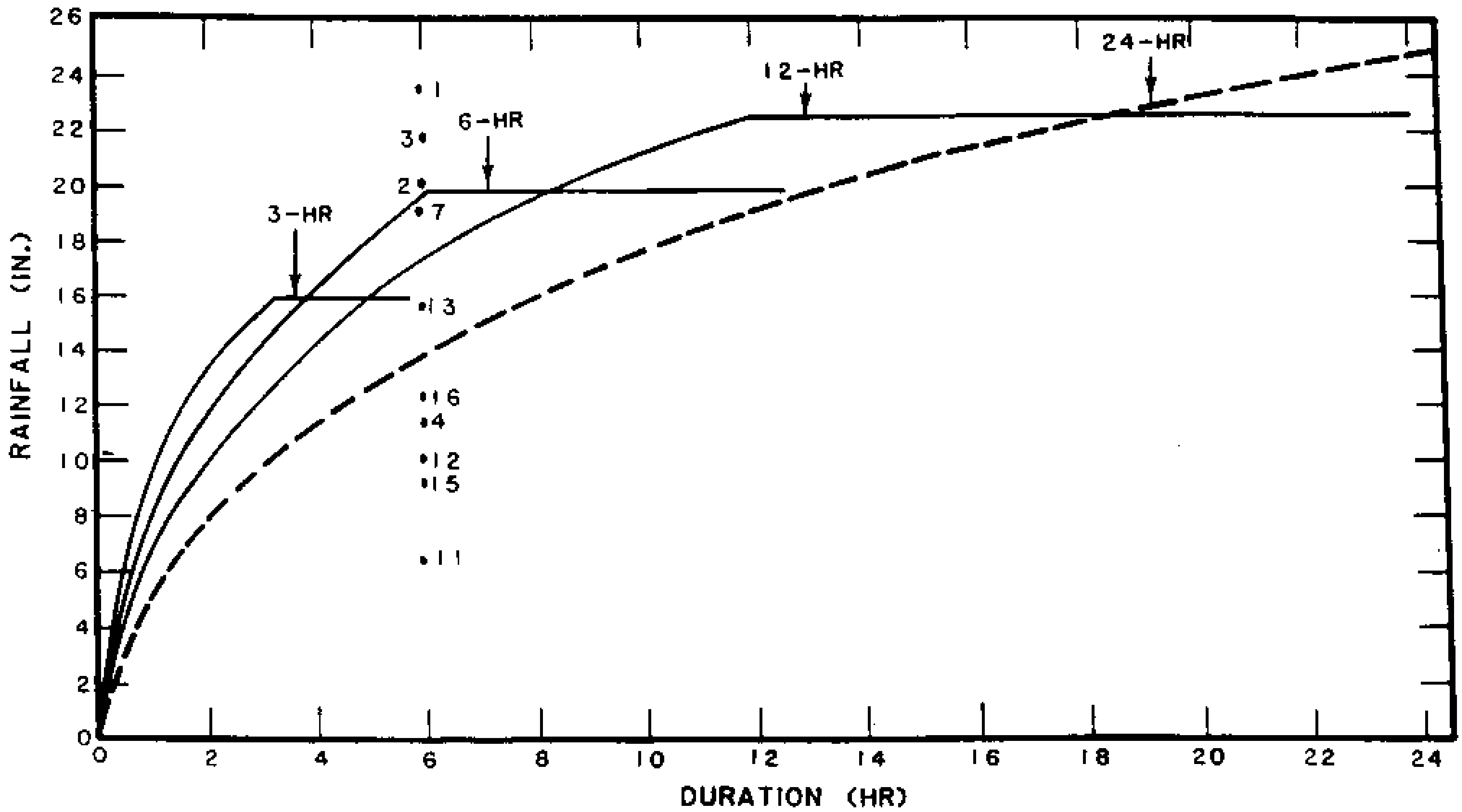


Figure 34.--Curves of figure 31 with supporting data for 24 hr.

The numbers in figure 32 to 34 represent those storms from table 5. Only those storms with appropriate storm data were plotted in figures 32 to 34. For example, if a particular storm had 1- and 3-hr data, then the 1- to 3-hr ratio could be computed; consequently this ratio was multiplied by the TVA 3-hr "intermediate" value in order to obtain the 1-hr value plotted in figure 32. The storm data for the other storms were plotted similarly.

A comparison of extreme 1-hr and 24-hr rain occurrences demonstrates the reasonableness of not specifying that a single enveloping depth-duration relation be used in TVA precipitation application. A summary of annual maximum 1-hr and 24-hr rains at Tennessee Basin stations is shown in figures 35 and 36, which show that the probability of the maximum 1-hr and the maximum 24-hr rains coming from the same storm is small. Such an occurrence is, therefore, appropriately assigned only to the rare PMP event, while a variable set of depth-duration criteria is suitable for the TVA precipitation event.

2.2.12 TVA Precipitation Depth-Duration Relations, Index Value Other Than 19.8 in.

As indicated previously in Figures 15 and 16, beyond the most intense portion of the storm both the PMP and TVA precipitation become increasingly topographically dependent. This is shown by the separation of the "smooth" and "rough" curves in figures 15 and 16. This variation requires that the TVA precipitation depth-duration relation be not only a function of storm duration, as discussed in preceding paragraphs, but also a function of index value (fig. 24 and 25). The requisite set of depth-duration curves, derived by interpolations from figures 15 and 31 are found in figures 37 to 40.

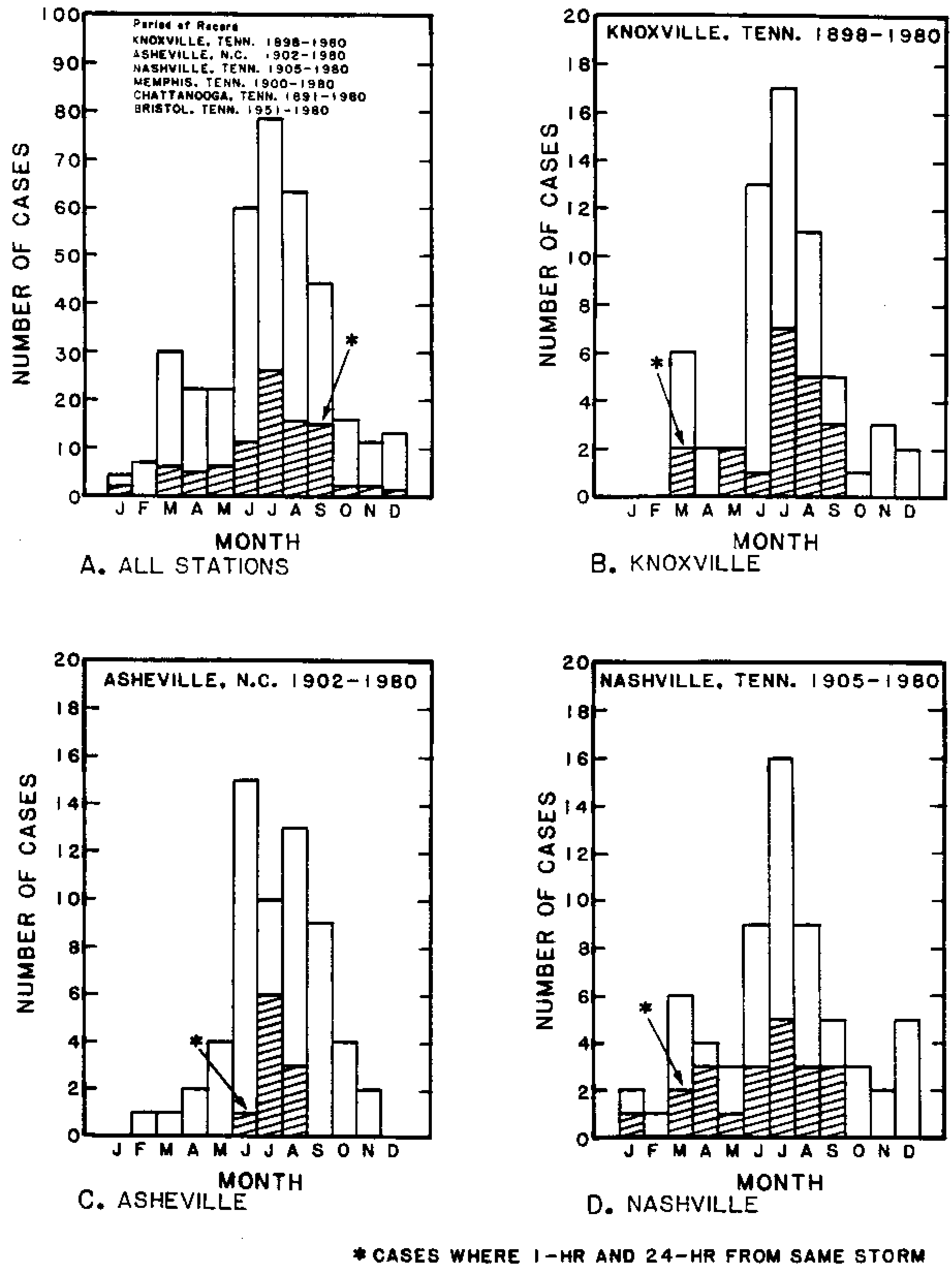


Figure 35.—Frequency distribution of annual maximum 1-hr rains (open) and joint occurrence of 1- and 24-hr rains in the same storm (A, all stations, B, Knoxville, C, Asheville, and D, Nashville).

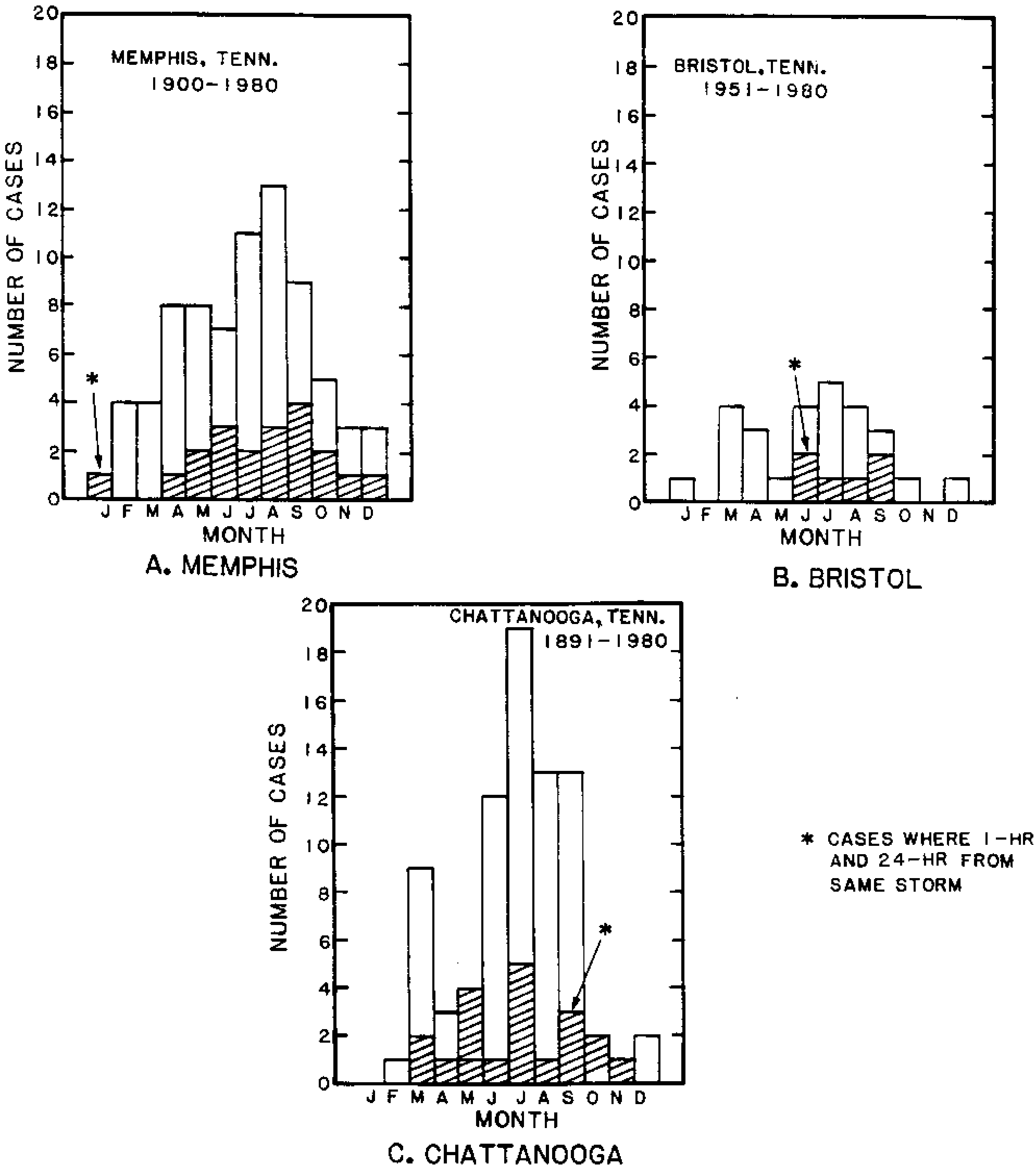


Figure 36.--Frequency distribution of annual maximum 1-hr rains (open) and joint occurrence of 1- and 24-hr rains in the same storm (A, Memphis, B, Bristol, and C, Chattanooga).

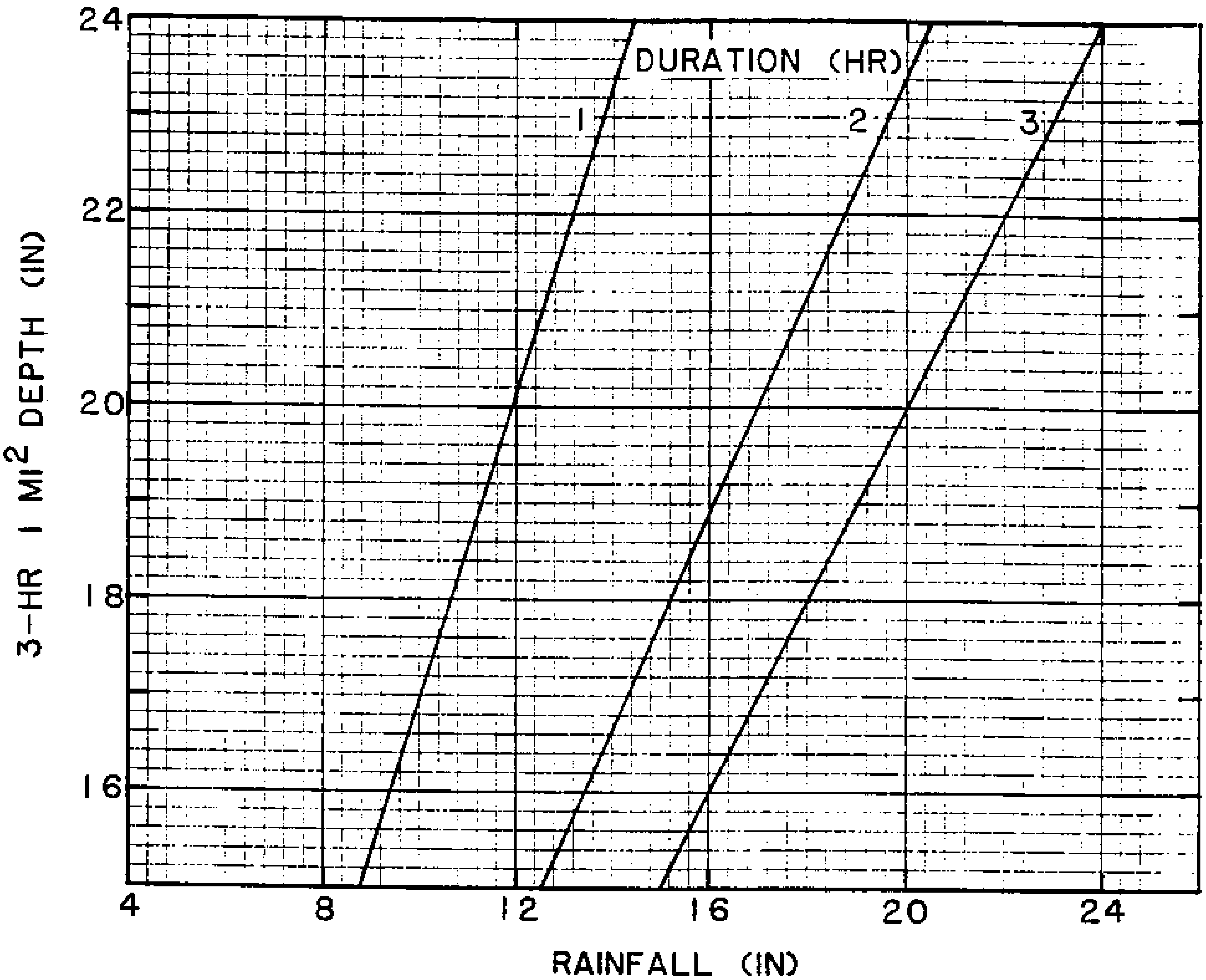


Figure 37.--Depth-duration relations for 3-hr TVA precipitation storm.

2.2.13 Depth-Duration Criteria for PMP

To obtain the durational distribution of the probable maximum precipitation for various index values (fig. 22 and 23), a procedure is followed allowing greater increases than for the TVA storm. Rainfall during the one time period does not necessarily preclude rain during a succeeding period. Following the procedure of HMR No. 33 (Riedel et al. 1956) and HMR No. 51, (Schreiner and Riedel 1978) a PMP storm is subdivided into durational increments in accordance with the enveloping depth-duration curve, such as figure 16 (sect. 2.2.7.1). For example, the 3-hr PMP is followed in the next 3 hr by the difference between 6-hr PMP and 3-hr PMP. The PMP depth-duration nomogram is shown in figure 41.

2.2.14 Temporal Distribution of Rainfall

Previous sections have dealt with magnitudes of temporal increments of TVA and PMP storms. This section specifies the arrangement of these increments into a sequence.

Extreme storms in Tennessee have generally been one-burst affairs in which little or insignificant rain follows the extreme 3-hr rainfall. Storm experience, in general, points to the occurrence of a 24-hr rainfall in a single burst. With this in mind, the following guidelines are suggested for the temporal distribution of the PMP and TVA rainfall.

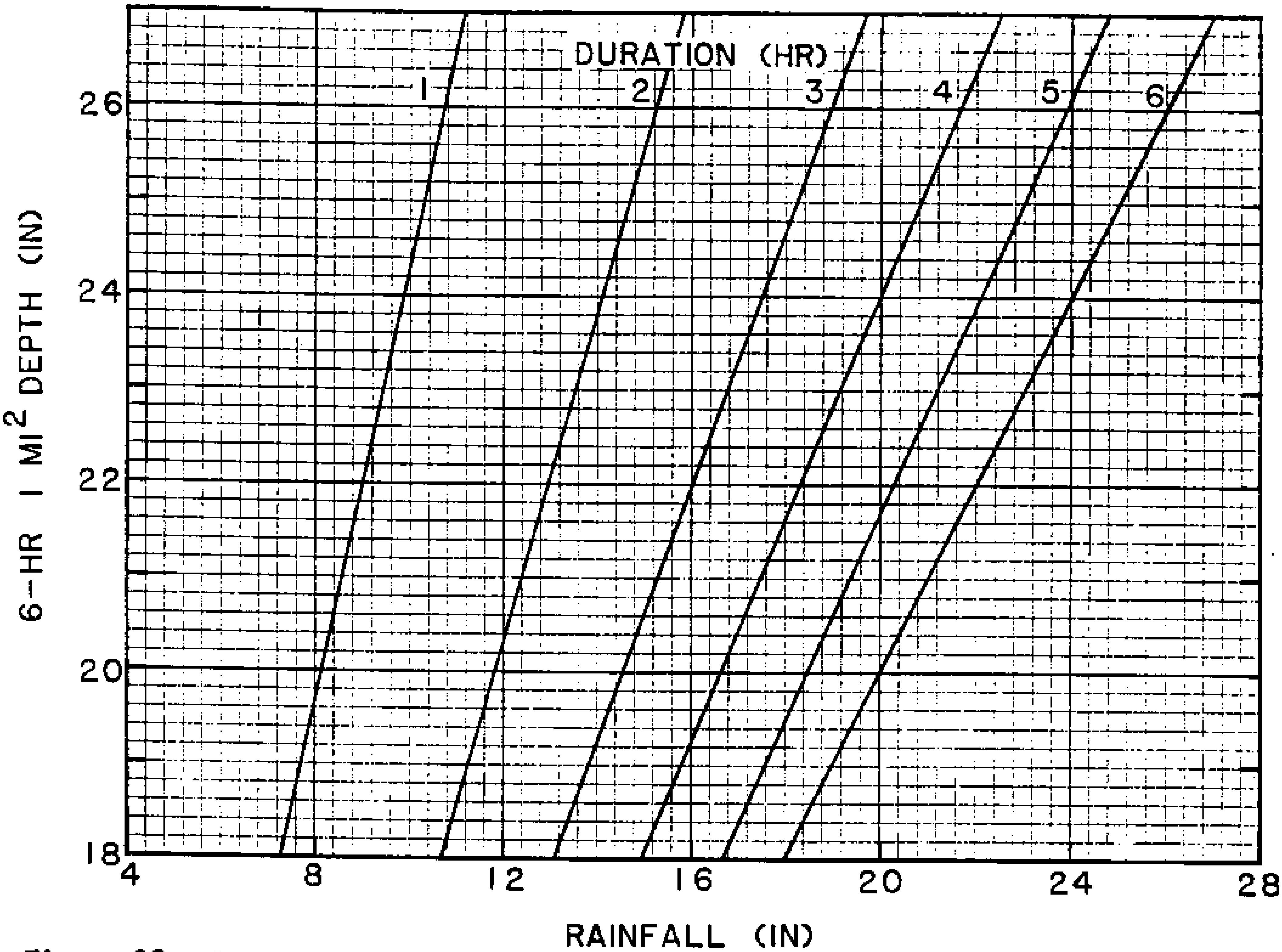


Figure 38.--Depth-duration relations for 6-hr TVA precipitation storm.

2.2.14.1 6-hr Rainfall Increments in 24-hr Storm. Arrange the four 6-hr increments such that the second highest increment is next to the highest, the third highest increment adjacent to these, and the fourth highest increment at either end. This still allows various arrangements, and the critical one is that which would yield the most critical hydrograph.

2.2.14.2 1-hr Increments in Maximum 6-hr Rainfall. Any arrangement of 1-hr increments is acceptable as long as the two highest hourly amounts are adjacent, the three highest hourly amounts are adjacent, etc.

2.3 Summary

In this chapter, development of the PMP and TVA precipitation storm type appropriate to the Tennessee River watershed small basin ($\leq$100 mi^2) was described. It was concluded that a thunderstorm is the most appropriate PMP-type storm in the Tennessee River watershed. This type of storm usually occurs between April and September, but the months of July and August are taken to be the months of small-basin PMP and TVA precipitation.

PMP depth-duration relationships through 6 hr were derived for small basins using the Smethport, PA and Holt, MO storms as anchor points for the "rough" and "smooth" terrain categories, respectively. To extend the depth-duration curves to 24 hr, data from appropriate PMP-type storms outside the Tennessee River

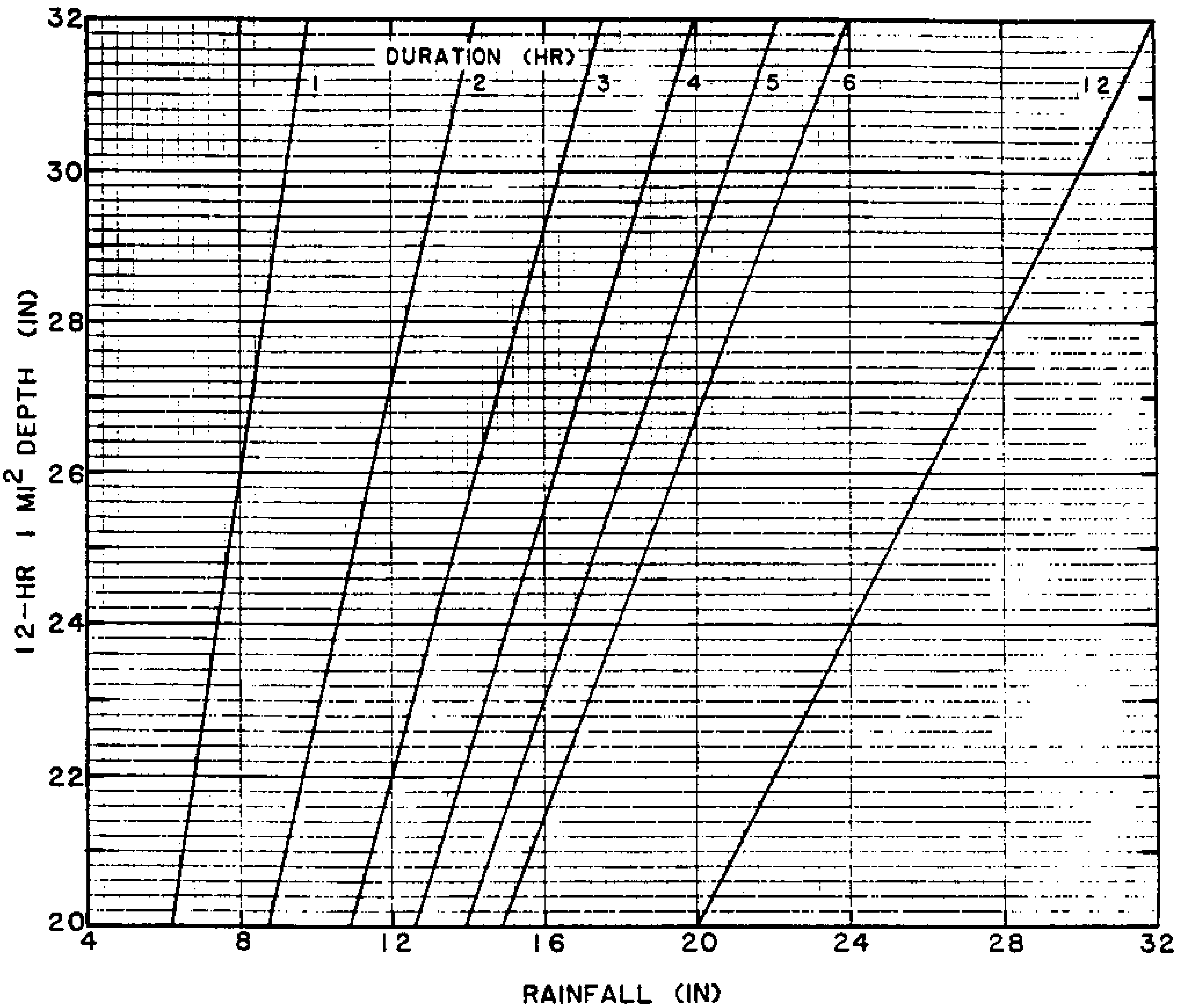


Figure 39.—Depth-duration relations for 12-hr TVA precipitation storm.

watershed were plotted at durations of 12, 18, and 24 hr and a curve of "best fit" was constructed. The adopted relations from 6 to 24 hr were applied to both the "rough" and "smooth" PMP categories.

In addition, using storms that have occurred within the Tennessee River watershed, depth-duration relations out to 24 hr for "rough-," "intermediate-," and "smooth-" terrain categories were derived for a lesser precipitation called TVA precipitation. Because the probability of a maximum 1-, 3-, 6-, or 24-hr maximum rain occurring within, coming from the same storm over any Tennessee River watershed is small, a variable set of depth-duration criteria was adapted for TVA precipitation.

Finally, depth-area and depth-duration nomograms were developed for the PMP and TVA precipitation which permit the user to obtain PMP and TVA precipitation estimates for durations of 1 to 24 hr and basin sizes of 1 to 100 mi^2.

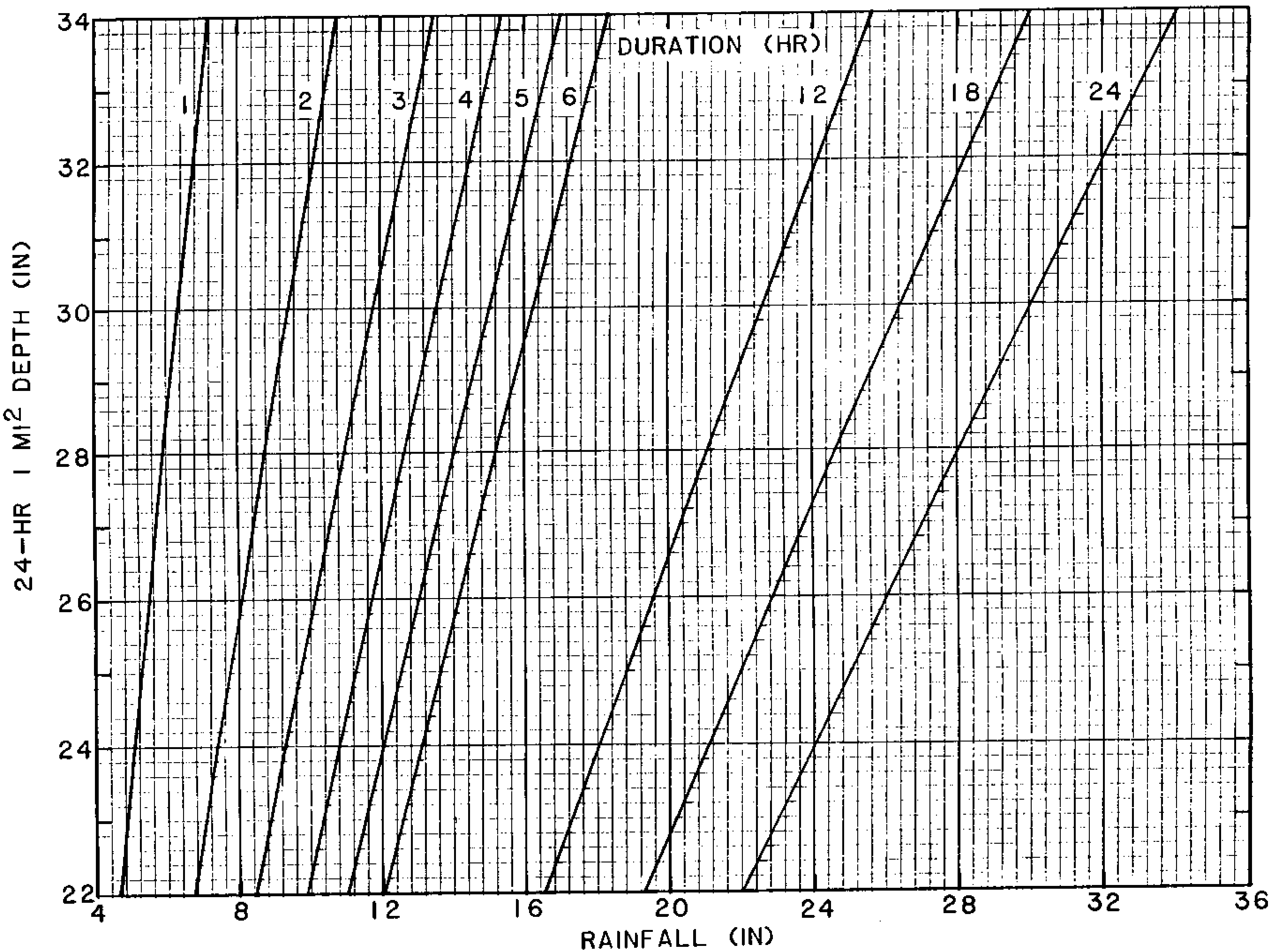


Figure 40.--Depth-duration relations for 24-hr TVA precipitation storm.

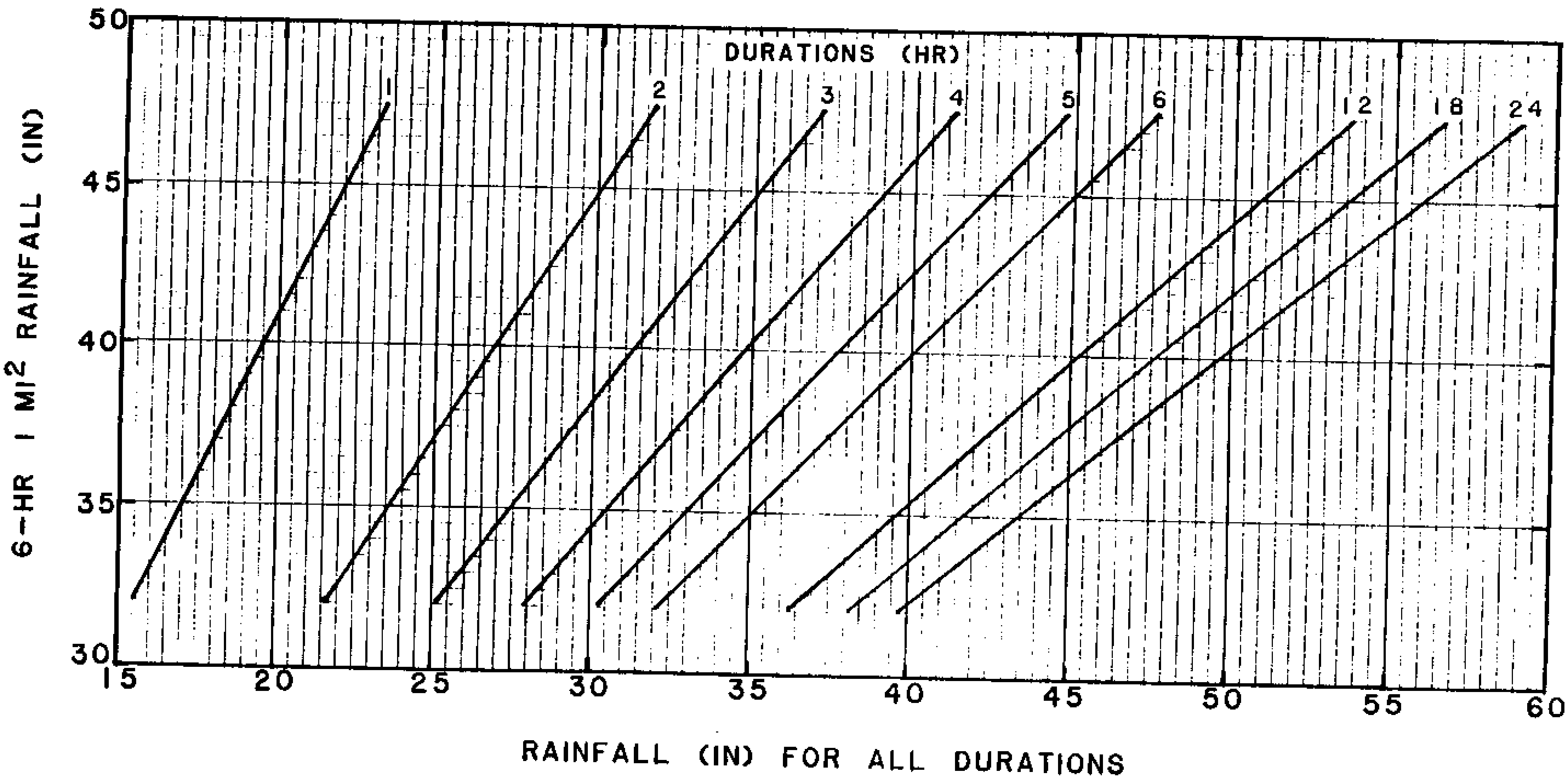


Figure 41.—Depth-duration nomogram for 24-hr PMP storm.

3. PMP AND TVA PRECIPITATION FOR 100 TO 3,000-MI^2 BASINS

3.1 Introduction

Chapter 2 provided a means of obtaining estimates of PMP and TVA precipitation for basins up to 100 mi^2 in area. In this chapter, a generalized description of the development used to obtain such estimates for drainages from 100 to 3,000 mi^2 in area is presented.

This chapter is divided into three sections. The first section describes meteorological characteristics of pertinent storms. The second section discusses the derivation of a generalized methodology used to obtain PMP and TVA precipitation estimates. Finally, the third section discusses solutions to the problem of differences that may arise in estimating PMP at the 100-mi^2 interface using the small and large basin procedures.

Because the eastern portion of the basin is more mountainous than the western portion and therefore exerts a more complicated control on precipitation, the procedures for obtaining generalized estimates differ between the mountainous east and the remainder of the Tennessee Valley region.

3.2 Storm Characteristics

3.2.1 Introduction

In chapter 2 of this report the PMP type warm-season small-area thunderstorm situation was described. In HMR No. 41 the winter-type PMP storm for basins of 8,000 mi^2 and larger was the main concern. Here we are concerned with the type or types of situations that will produce PMP and TVA precipitation values over intermediate-size basins between 100 and 3,000 mi^2.

A variety of specific rain-producing mechanisms may be involved in the PMP or TVA precipitation over a 3-day period. A decadent tropical storm or hurricane may or may not be involved. Relevant storms are discussed in the following sections.

3.2.2 Summer Control of Maximum United States Rainfall

Maximum observed rainfall near the Gulf Coast occurs in summer for areas up to at least 2,000 mi^2. The maximum observed values from "Storm Rainfall" (U.S. Army 1945-) are listed in table 8. All table 8 values, except those for 6 hr, are from the Yankeetown, FL, hurricane "Easy" storm of September 3-7, 1950. The 6-hr values are from the Thrall, TX storm of September 8-10, 1921.

A hurricane like the Altapass, NC Storm of July 1916, may best typify the PMP storm for the mountainous eastern portion of the Tennessee watershed. The remaining two-thirds of the Tennessee watershed may also be influenced by decadent tropical storms or hurricanes (Neumann et al. 1978). Figures 42 and 43, reproduced from HMR No. 41 (Schwarz 1965) (fig. 3-20 and 3-21), show some typical tracks of past tropical storms. However, the distance of the Tennessee watershed from the ocean source increases the chance that a more complex weather situation than a decadent tropical storm alone is the cause of the 3-day PMP or TVA precipitation. The record-breaking rains in the Tennessee Basin mountains in late September and early October 1964 were produced by a storm which will be used to demonstrate this point.

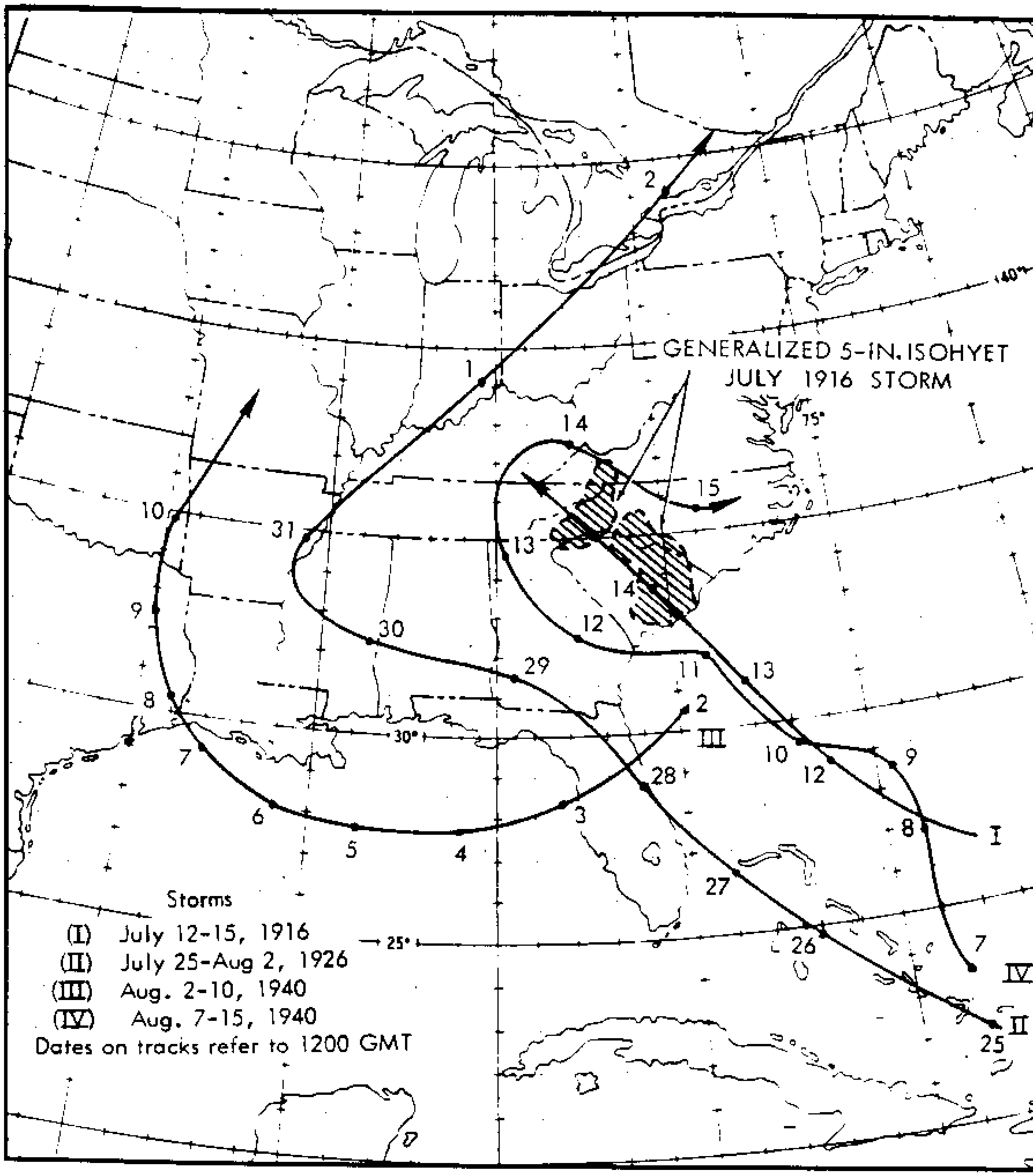


Figure 42.—Hurricane tracks from the Atlantic Ocean.

Table 8. Maximum observed United States rainfall (in.)

Area (mi^2)	Duration (hr) 6	12	18	24	36	48	72
200	17.9	25.6	31.4	34.2	36.7	37.7	39.2
500	15.4	24.6	29.7	32.7	35.0	36.0	37.3
1000	13.4	22.6	27.4	30.2	32.9	33.7	34.9
2000	11.2	17.7	22.5	24.8	27.3	28.4	29.7

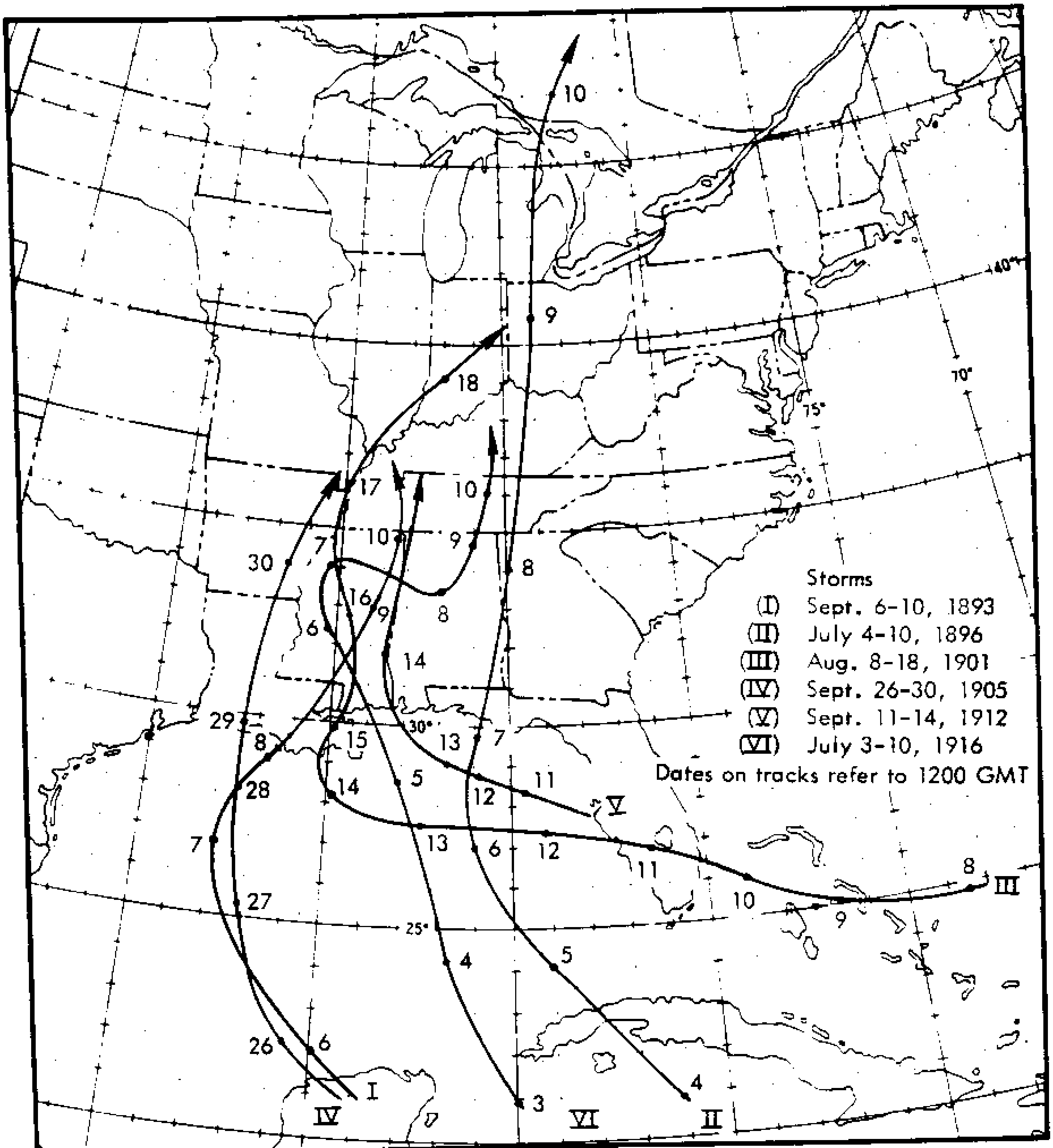


Figure 43.--Hurricane tracks from a southerly direction.

3.2.3 September 28-October 4, 1964 Storm Period

This "storm" affected the mountainous eastern portion of the Tennessee River basin and demonstrates a combination of types that gave heavy total precipitation over 6 days. Separate types of events produced about equally heavy 24-hr rains at the same location within this storm period. The first of the two storms dumped its rain on September 28-29, while the remnants of hurricane Hilda added more rain on October 4-5. Figures 44 through 49 are presented to help clarify the narrative discussion.

The TVA has published a fairly comprehensive account of the floods of September and October 1964 (TVA 1965). A few of the highlights of the associated storm events as listed at the beginning of the TVA report are summarized here:

1. The most significant rain was "...along the crest of the Blue Ridge in western North Carolina and northern Georgia."

2. Rosman, NC established new rainfall records with a total accumulation from September 28-October 4, of 35.4 in.

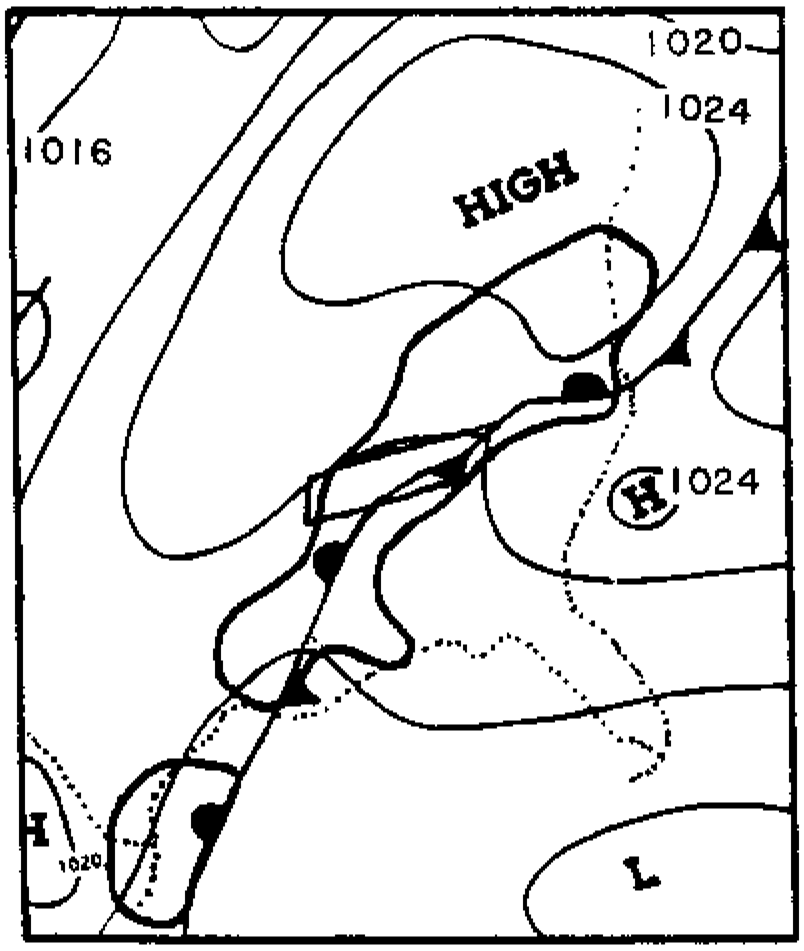
3. In the second half of the storm period, "...floods in the upper French Broad River basin were the highest since 1916 on most streams." Also, "On the upper Little Tennessee river the flood exceeded the highest previously known flood...."

A high volume of nonorographic rainfall was made possible in the September 28-29 storm by a large low-level transport of moisture into an area of low-level convergence associated with an inverted-V trough and a quasi-stationary front. This type is a classic producer of heavy rain throughout the central United States. Added to the low-level convergence mechanism in this storm was an orographic upslope influence as evidenced by the primary rain center near Rosman, NC.

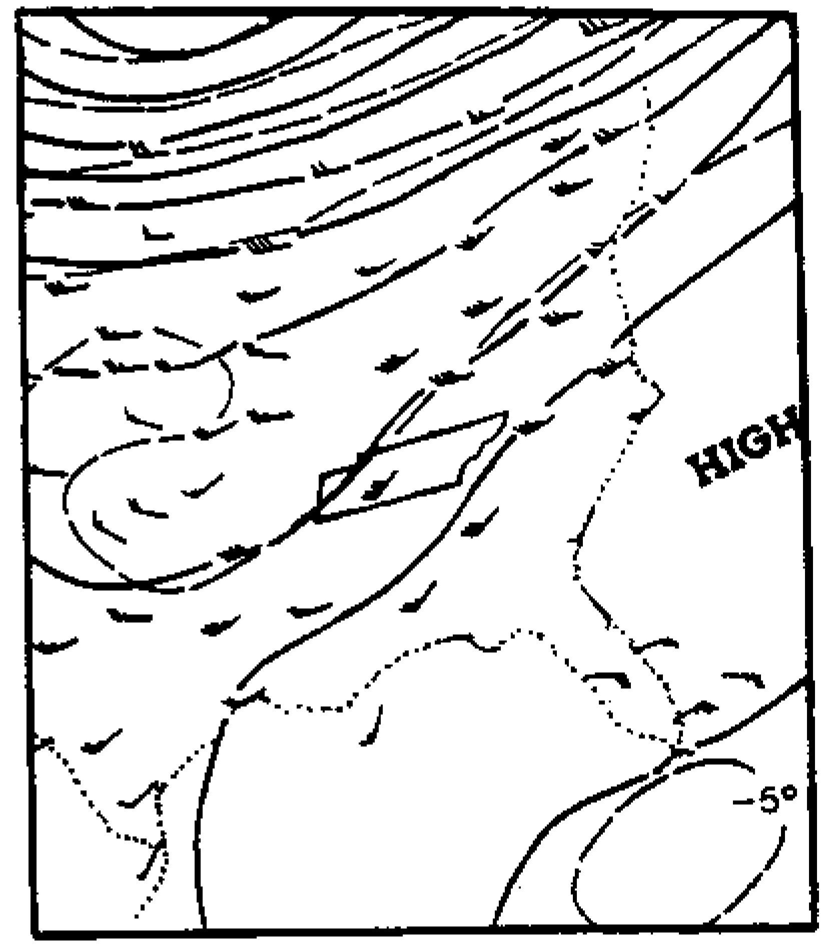
The 500 mb charts (figs. 44 and 45) show a trough in the westerlies which did not extend its influence to the vicinity of the hurricane. This synoptic picture permitted the hurricane to continue at a rather slow rate. Had a major trough entered the area the hurricane would have likely turned to a northeasterly course and increased its speed so that the rain would not have fallen over the same area as the observed heavy rain. Such a "fixing" of the broadscale synoptic features is extremely important for heavy rains to repeat over approximately the same area. See, for example, the discussion on pages 3-4 of HMR No. 38 (Schwarz 1961).

That the persisting, or geographically fixed, influx of very moist air was an important feature of the repeating heavy rains of September 28-October 4 is demonstrated by figures 48 and 49. Highlighted on figure 48 is the pronounced 850-mb tongue of moisture extending toward the eastern border of Tennessee. Based on the evaluation of the Showalter Index (Showalter 1953), figure 49 shows that the most unstable region was centered from northern Alabama into eastern Tennessee in conjunction with persisting high values of precipitable water. (A Showalter index of zero represents a marked degree of instability since this is an average for the whole storm period.) The precipitable water values in figure 49 are also for the period September 28-October 4, so their magnitude must be judged accordingly. Figure 50 provides a basis for judgment, giving the climatic assessment of precipitable water values for an atmospheric sounding station south of the Tennessee Basin. The 12-hr persisting dew point data in figure 50 are from charts developed in the Hydrometeorological Branch and published in the National Climatic Atlas (Environmental Data Service 1968). Their precipitable water equivalent is based on an assumed saturated atmosphere. The 100-yr values of precipitable water, as well as the maximum precipitable water of record (fig. 50), are derived from twice-a-day precipitable water measurements for Montgomery, AL, for the period 1949-1973.

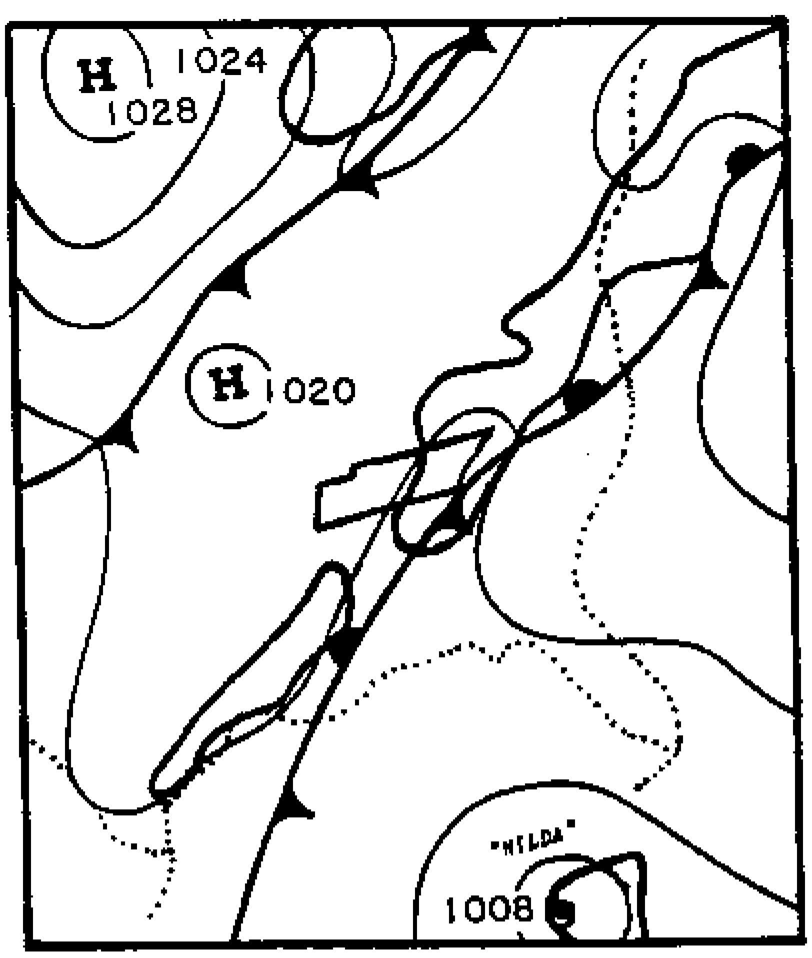
For a portion of the 1964 storm period, surface dew points of 74°F were observed near the Gulf Coast, while on October 2, Burrwood, LA observed a precipitable water value of 2.34 in. (O'Connor 1965).



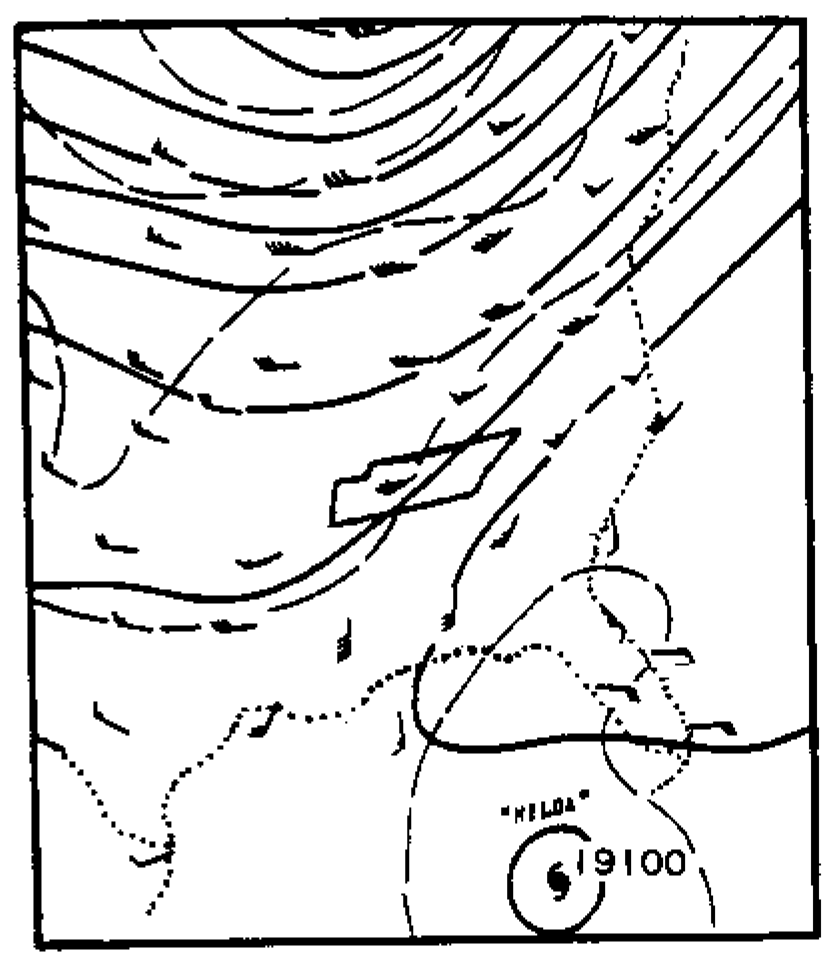
SEPT. 28, 1964 Surface 1800GMT



SEPT. 28, 1964 500mb 0000GMT



SEPT. 29, 1964 Surface 1800GMT

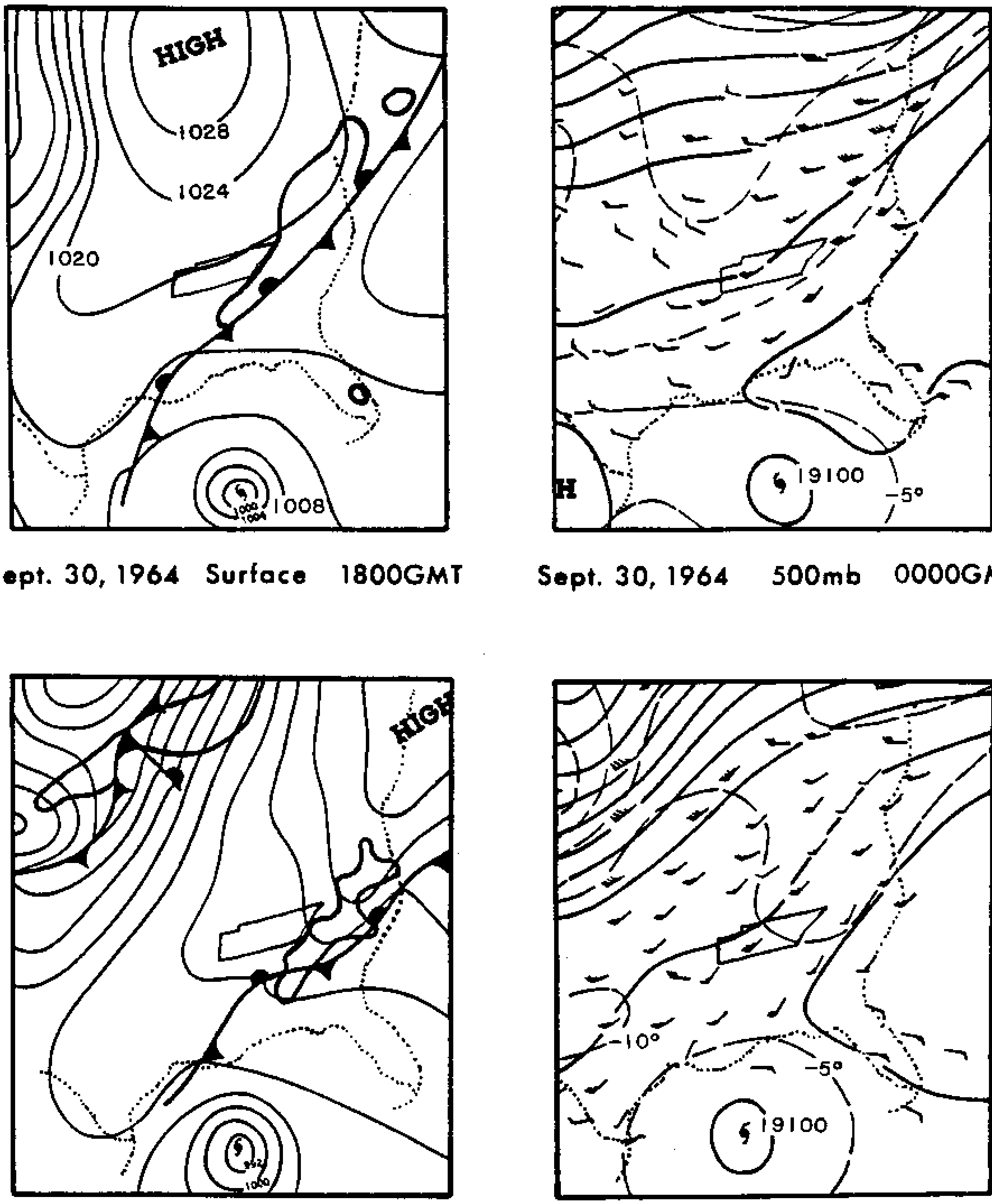


SEPT. 29, 1964 500mb 0000GMT

Figure 44.--Surface and upper-air weather maps for September 28-29, 1964.

3.2.4 Season of Large-Area PMP and TVA Precipitation

Guidance for assigning the season for the all-season PMP and TVA precipitation determined in this report is taken from the monthly analyses of maximum persisting 12-hr dew point (Environmental Data Service 1968). Sustained high moisture inflow is one of the most important criteria for large area precipitation. The curves in figure 50 are typical of the seasonal distribution of maximum moisture to the south and southwest of the Tennessee Valley. From these analyses, it is apparent that the maximum persisting 12-hr dew point occurs in the months of June through September. It is at a maximum in July, but



Sept. 30, 1964 Surface 1800GMT

Sept. 30, 1964 500mb 0000GMT

Oct. 1, 1964 Surface 1800GMT

Oct. 1, 1964 500mb 0000GMT

Figure 45.—Surface and upper-air weather maps for September 30-October 1, 1964.

essentially the same from June to August. It decreases slightly from August to September. The approximate 100-yr precipitable water is at maximum from August to September. There is a small increase from July to August. June and October are at about the same level.

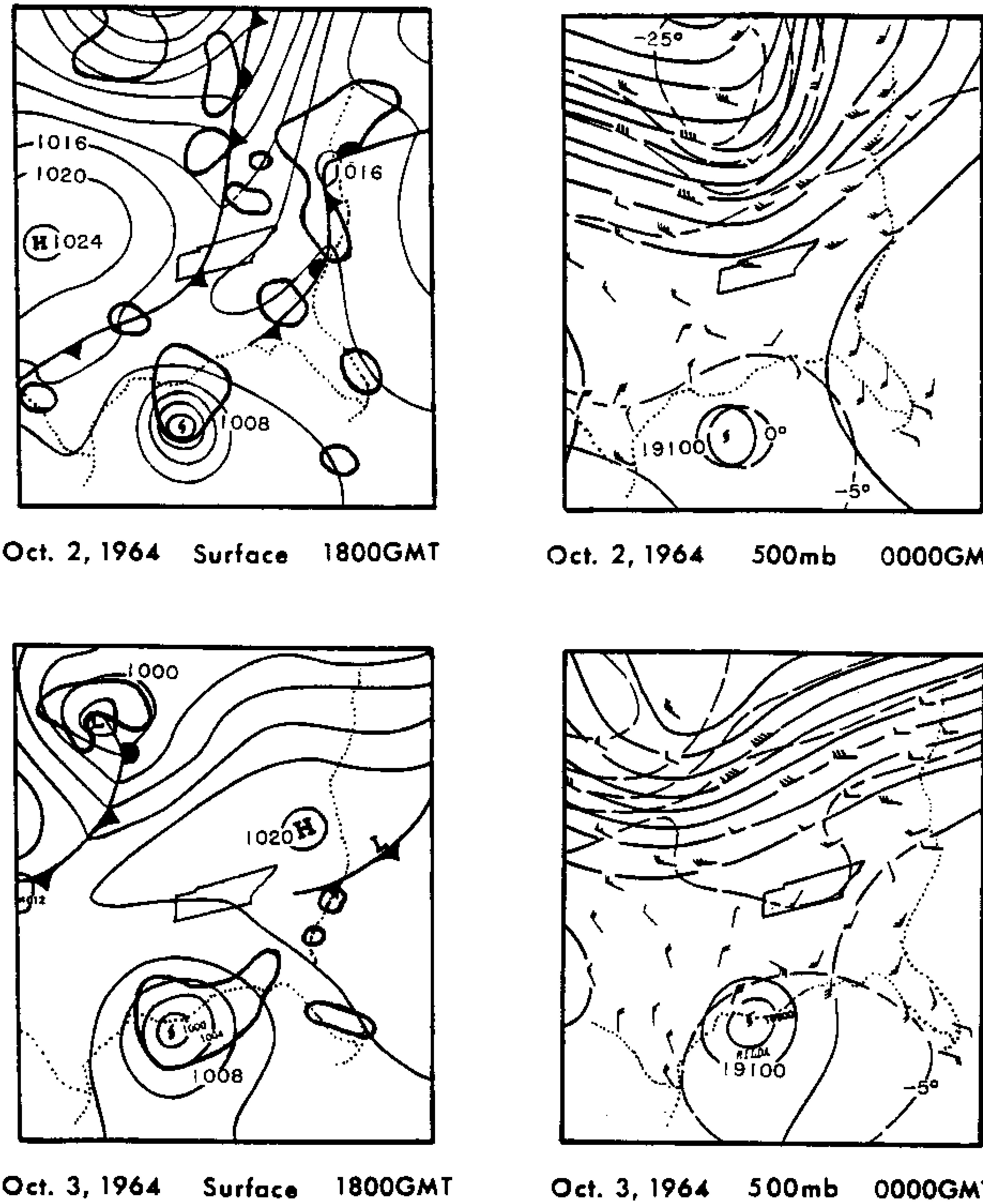
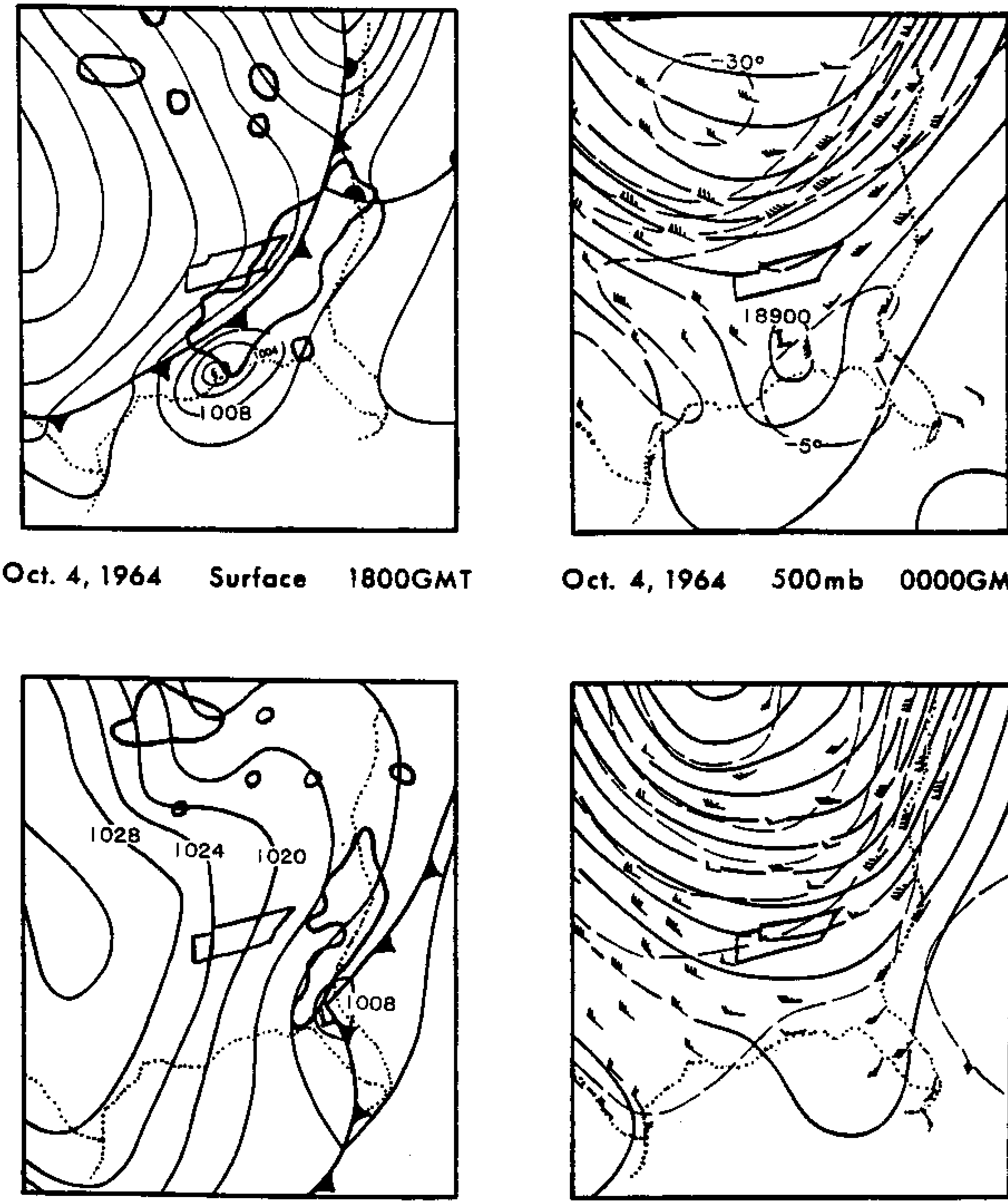


Figure 46.--Surface and upper-air weather maps for October 2-3, 1964.

3.3 Nonorographic PMP and TVA Precipitation

3.3.1 PMP Depth-Area-Duration Values

Estimates of probable maximum precipitation for basins between 100 and 3,000 mi^2 in the central and eastern United States are generally based on moisture maximization, transposition, and envelopment of storm values (Myers 1967 and Schreiner and Riedel 1978). Another method in which direct transposition was not used was applied in HMR No. 41 (Schwarz 1965) for estimating basic nonorographic PMP values for selected drainages between 8,000 and 21,000 mi^2



Oct. 4, 1964 Surface 1800GMT

Oct. 4, 1964 500mb 0000GMT

Oct. 5, 1964 Surface 1800GMT

Oct. 5, 1964 500mb 0000GMT

Figure 47.--Surface and upper-air weather maps for October 4-5, 1964.

above Chattanooga. In HMR No. 41, moisture-maximized values for selected area sizes and durations were plotted on maps at the various storm locations and enveloping isohyets constructed. Since actual storms are not directly transposed, it is only through regional, areal, and durational smoothing of the enveloped values that result in an implicit envelopment and transposition.

The same technique was used here. Analyses such as those in HMR No. 41 figure 5-3 cited above were constructed for a number of area sizes and durations. As an example, the analysis chart for 2,000 mi^2 and 24 hr is reproduced in figure 51. The basic data are listed in table 9. Note that the isohyets in figure 51

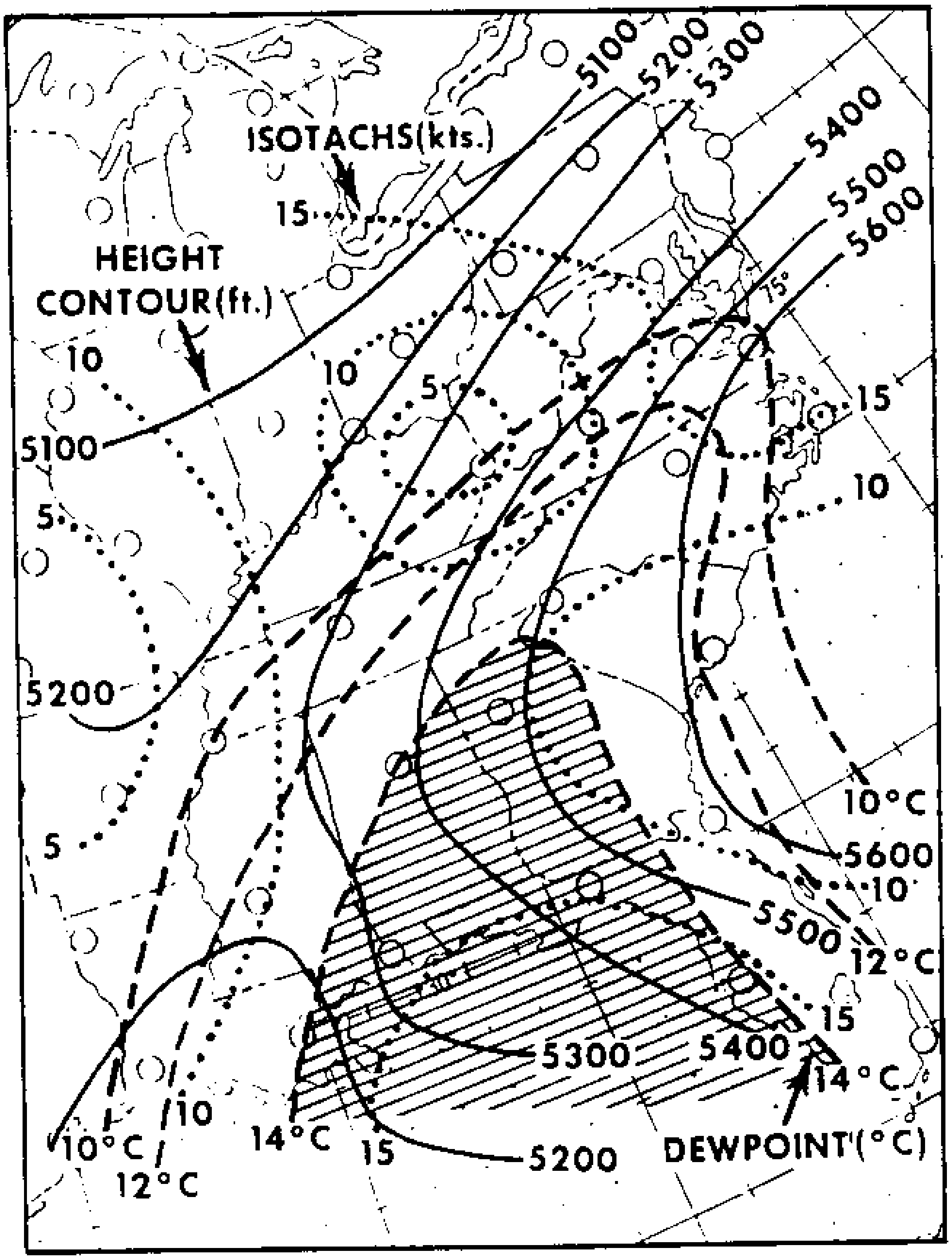


Figure 48.--Composite 850-mb (5,000-ft) chart for September 28-October 4. 1964.

represent a minimum envelopment of storms moisture maximized in place. (This map includes storms at all seasons while figure 5-3 of HMR No. 41 is only for the cool season.) Maps such as figure 51 need to be smoothed regionally, areally, and interdurationally before they can be regarded as PMP.

Scaling values from the final smoothed set of maps at Knoxville Airport leads to an array of basic PMP depth-area-duration values (fig. 52). In this figure, midwestern intense storms, particularly at Bonaparte, IA in June 1905 and at Hallett, OK in September 1940, have the biggest influence on the 6-hr values. Hurricanes exercise the most influence at intermediate durations; these include both the Gulf of Mexico hurricanes and the Jefferson, OH storm of September 1878, (a hurricane that passed from the Atlantic Ocean northwestward across the Appalachian Mountains).

Another type of storm from table 9 which had significant influence on Knoxville PMP values in figure 52 was the Elba, AL storm. This storm, which occurred over a 5-day period between March 11 and March 16, 1929, covered a 100,000-mi^2 area from Mississippi to South Carolina. The synoptic features of the storm were

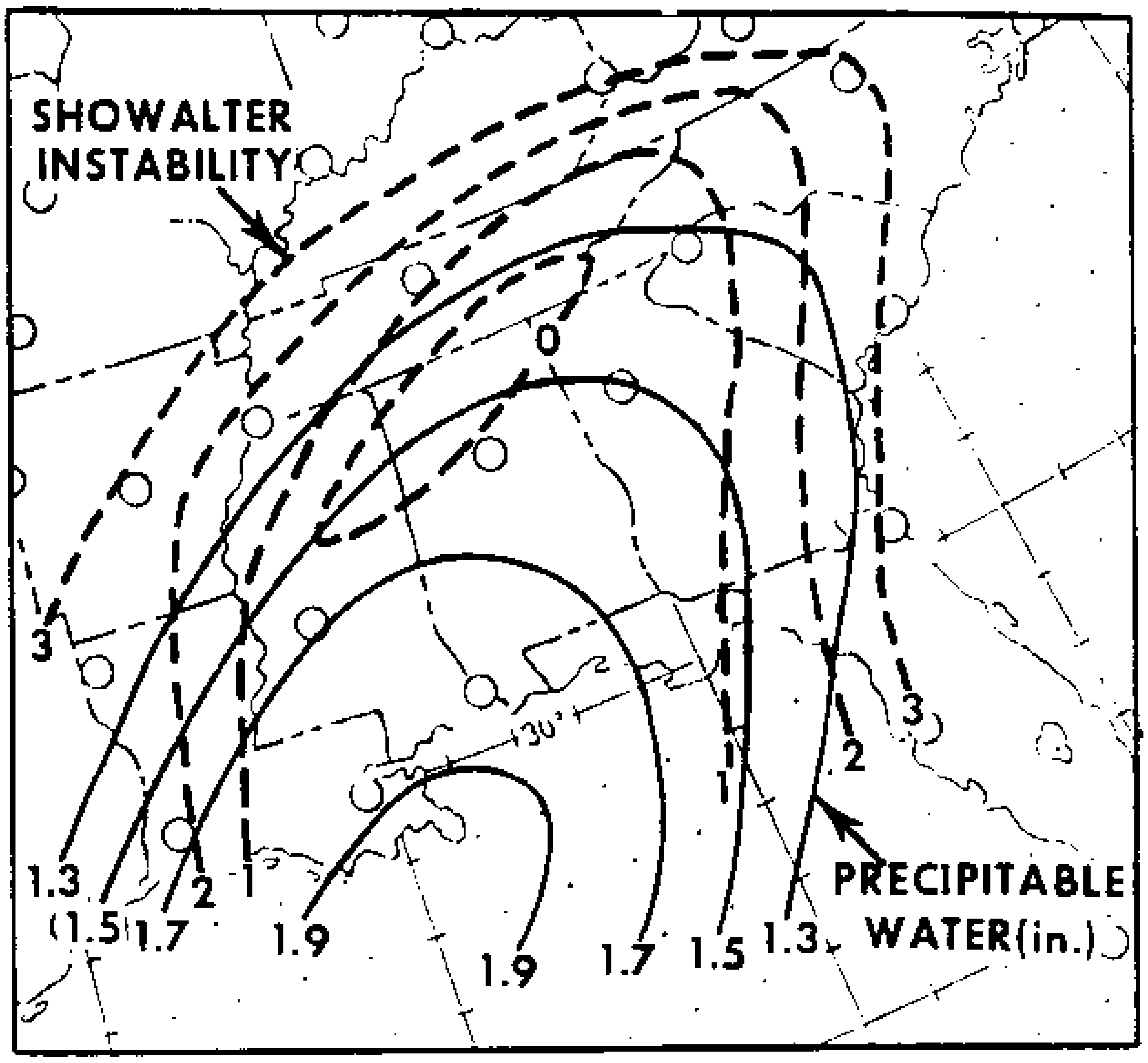


Figure 49.--Composite moisture-instability chart for September 28-October 4, 1964.

common to storms producing significant amounts of precipitation in early spring or early fall in the southeastern United States; namely a low pressure system associated with moist southerly flow colliding with cooler air to the north. Areas that are in the "warm sector" of these low pressure systems are especially susceptible to large amounts of precipitation; for example, in this storm Elba received nearly 30 in. of precipitation in almost 48 hr.

A table of PMP depth-area-duration values for the location of Knoxville Airport (from fig. 52) is shown in section 5.5.2 (p. 144). These values will be needed in the computational procedure for PMP, discussed in Chapter 5.

3.3.2 TVA Depth-Area-Duration Values

Figure 53 shows the basic TVA precipitation depth-area-duration values for the location of Knoxville Airport. These were derived in a manner analagous to the PMP values of figure 52, with omission of the moisture maximization step and with some undercutting of storm values that occurred at some distance from the Tennessee River basin. Depth-area-duration data for the July 5-10, 1916 hurricane (U.S. Army 1945-) have been adjusted by 0.70 (from fig. 5-4 HMR No. 41, Schwarz 1965), and are plotted in the diagram for comparison.

3.3.3 Basin-Wide Variation of Nonorographic PMP and TVA Depth-Area-Duration Values

The 24-hr 1,000-mi^2 isohyets (not shown), similar to figure 51, are converted to a percentage of values at Knoxville Airport, figures 54 and 55. The gradients of PMP and TVA precipitation for the basin sizes and durations that are the

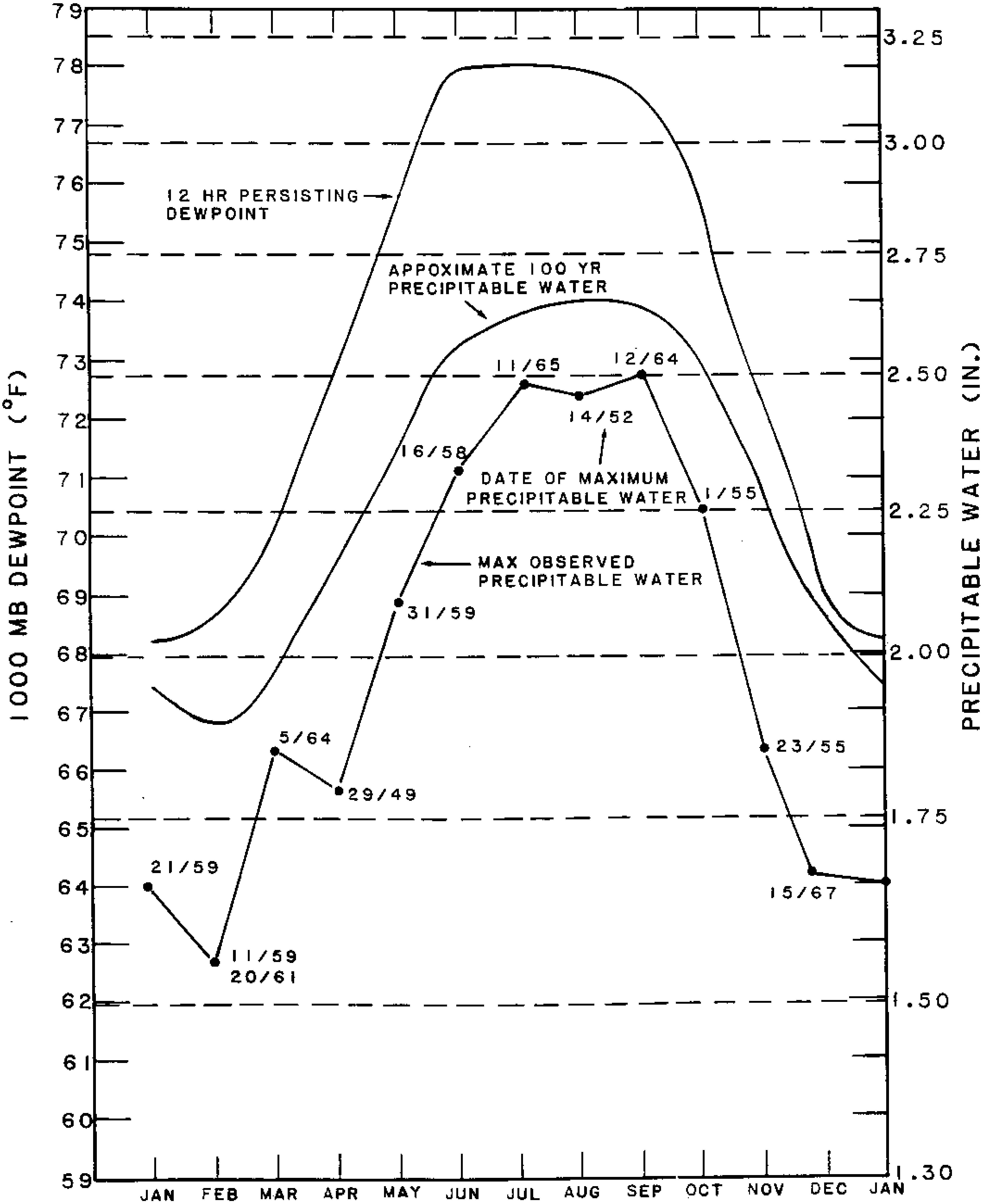


Figure 50.—Seasonal variation of maximum moisture, Montgomery, AL.

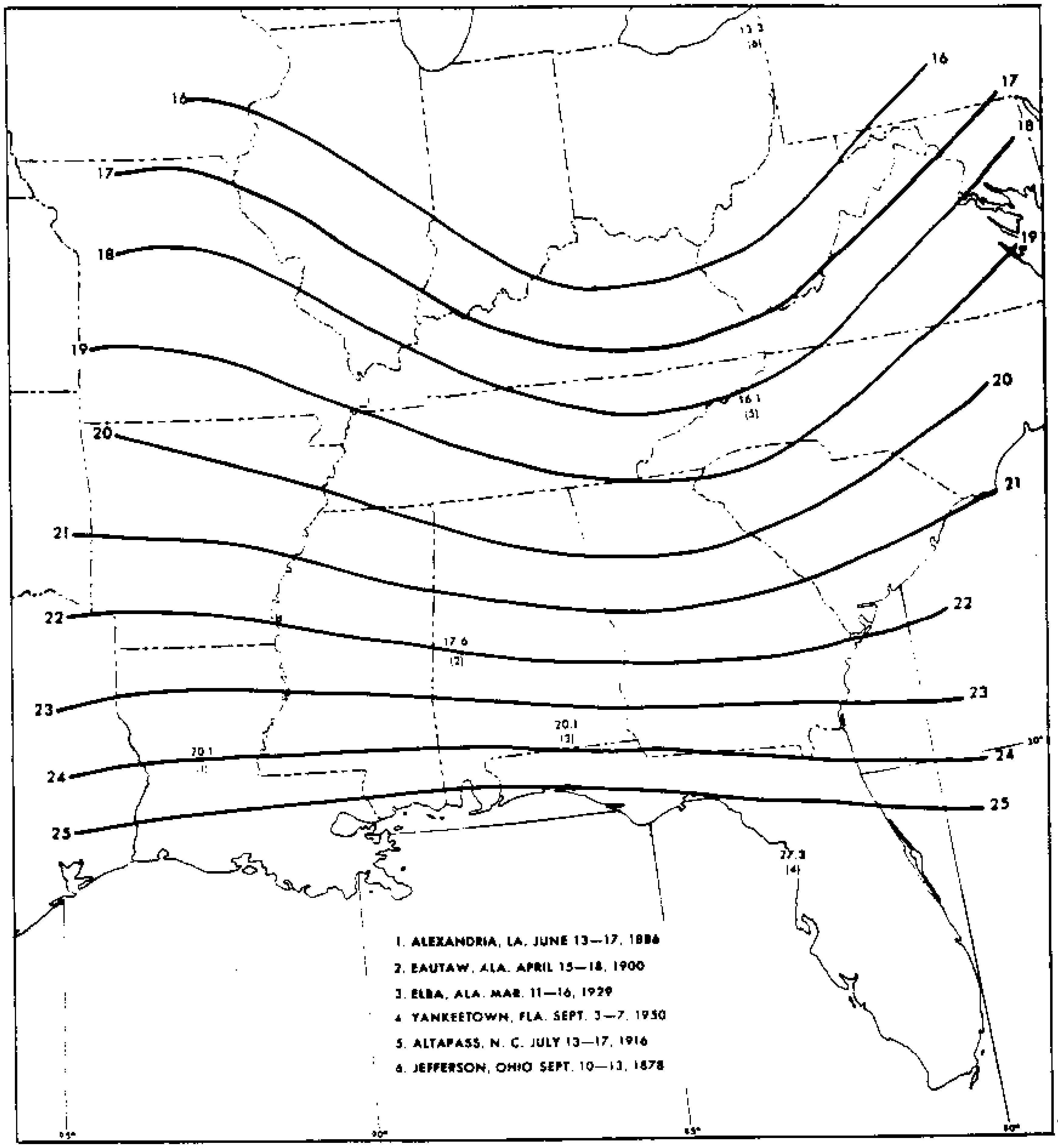


Figure 51.--24-hr 2,000-mi^2 PMP (in.).

subject of this chapter are relatively uniform over the Tennessee Valley. Figures 52 and 53 can be used as index charts for the full range of sizes ($\geq$100 mi^2) and durations ($\geq$6 hr covered in this report). Multiplication of the depth-area-duration values for PMP, (fig. 52) and for TVA precipitation (fig. 53) by the percentages shown in figures 54 or 55 yield respective nonorographic values throughout the basin.

Adjustments for orographic influences in the mountainous and nonmountainous eastern portion of the basin are described in sections 3.4 and 3.5. These sections also discuss effects of terrain roughness in adjusting the level of PMP and TVA precipitation in the entire Tennessee River Valley.

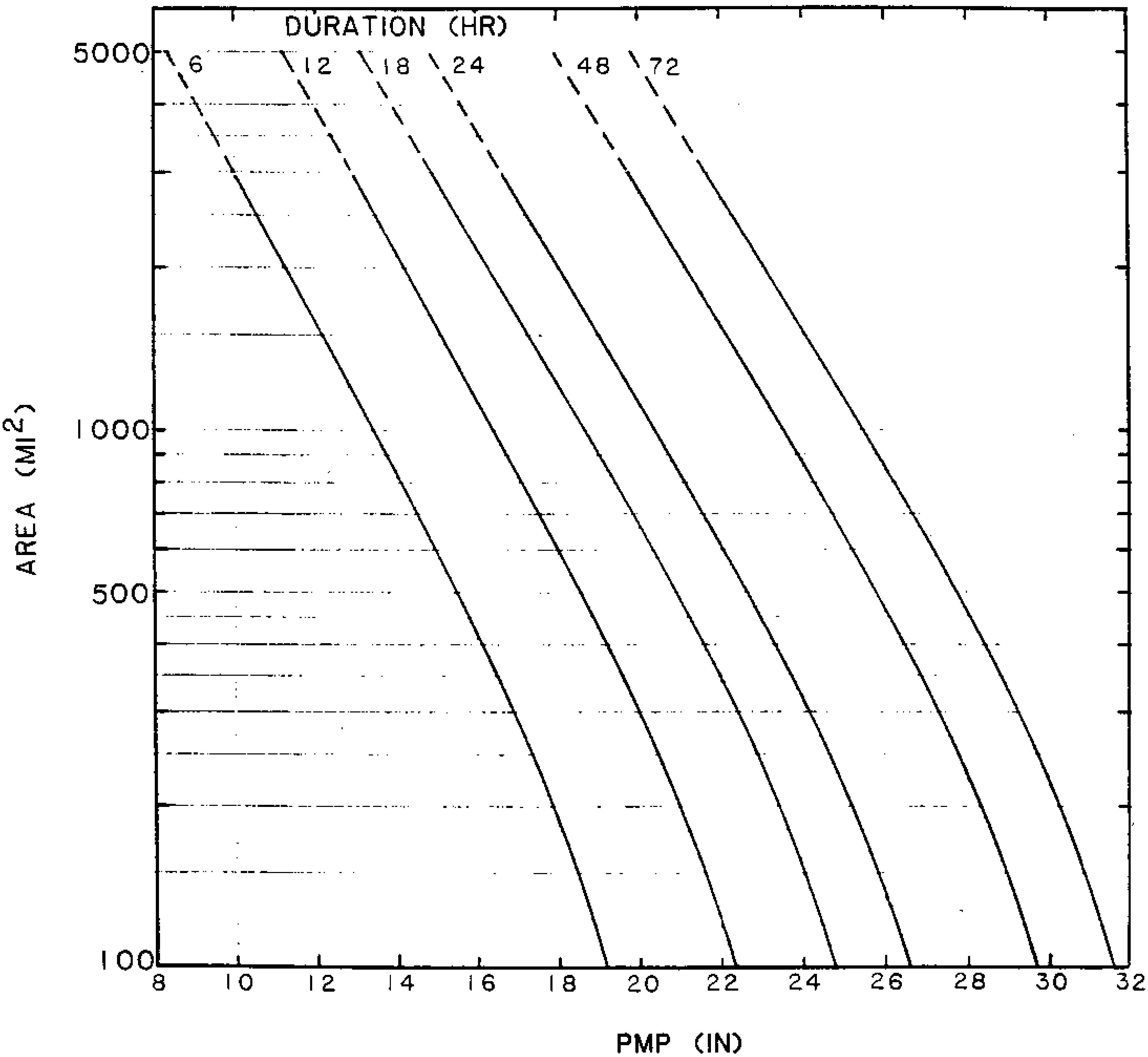


Figure 52.--Depth-area-duration curves for PMP at Knoxville Airport. Curves extrapolated from 3,000 to 5,000 mi^2.

3.4 Orographic Influence on PMP and TVA Precipitation

Five indicators of the orographic influence on the precipitation in the eastern part of the basin were developed to provide guidance in preparation of the generalized procedure and also the specific basin estimates given in chapter 6. These indicators are (1) mean annual precipitation, (2) 2-yr 24-hr precipitation frequency maps, (3) extreme monthly rains in subbasins, (4) small-basin PMP, and (5) optimum wind direction.

Table 9. Maximum observed and moisture-maximized storm rainfall for 24 hr over 2,000 mi^2

Date	Storm Center	Obs. Amt. (in.)	Moist.-Max Amt. in Place (in.)
9/10-3/13/1878	Jefferson, OH	10.4	12.7
6/13-17/1886	Alexandria, LA	17.3	20.1
6/27-7/1/1899	Hearne, TX	19.0	22.0
4/15-18/1900	Eutaw, AL	10.8	17.6
10/7-11/1903	Cortland, NY	10.2	15.1
8/28-31/1911	St. George, GA	11.3	13.7
3/24-28/1914	Merryville, LA	10.1	19.1
9/28-30/1915	Franklinton, LA	11.4	13.2
7/5-10/1916	Bonifay, FL	14.6	16.1
7/13-17/1916	Altapass, NC	13.3	16.1
9/8-10/1921	Thrall, TX	20.6	21.6
9/13-17/1924	Beaufort, NC	10.7	13.7
10/4-11/1924	New Smyrna, FL	11.9	14.4
4/12-16/1927	Jeff. Plaq. Drain. Dist., LA	13.3	16.2
6/1-5/1928	Thomasville, AL	10.9	14.0
9/16-19/1928	Darlington, SC	10.3	12.5
3/11-16/1929	Elba, AL	15.0	20.1
9/23-28/1929	Washington, GA	12.1	14.6
6/30-7/2/1932	State Fish Hatchery, TX	16.9	19.6
8/30-9/5/1932	Fairfield, TX	12.8	14.1
7/22-27/1933	Logansport, LA	13.0	14.3
12/5-8/1935	Satsuma, TX	11.9	18.6
6/27-7/4/1936	Bebe, TX	12.2	12.2
9/14-19/1936	Broome, TX	11.6	12.2
8/6-9/1940	Miller Island, LA	16.7	18.6
9/2-6/1940	Hallet, OK	10.7	15.1
10/17-22/1941	Trenton, FL	15.2	17.6
7/17-18/1942	Smethport, PA	10.2	11.2
9/3-7/1950	Yankeetown, FL	24.8	27.3
6/23-28/1954	Vic Pierce, TX	14.7	17.1
9/19-24/1967	Falfurrias, TX	10.4	12.1
8/19-20/1969	Tyro, VA	10.9	11.4
6/19-23/1972	Zerbe, PA	11.4	13.8

3.4.1 Mean Annual Nonorographic and Orographic Precipitation

Figure 56 is a mean annual precipitation chart for the Tennessee River basin (Tennessee Valley Authority, 1969). To indicate the influence of orography on the mean annual values, a hypothetical mean annual nonorographic precipitation chart is needed. Such a chart is shown in figure 57 and is derived by extrapolating mean annual precipitation values from areas outside the immediate

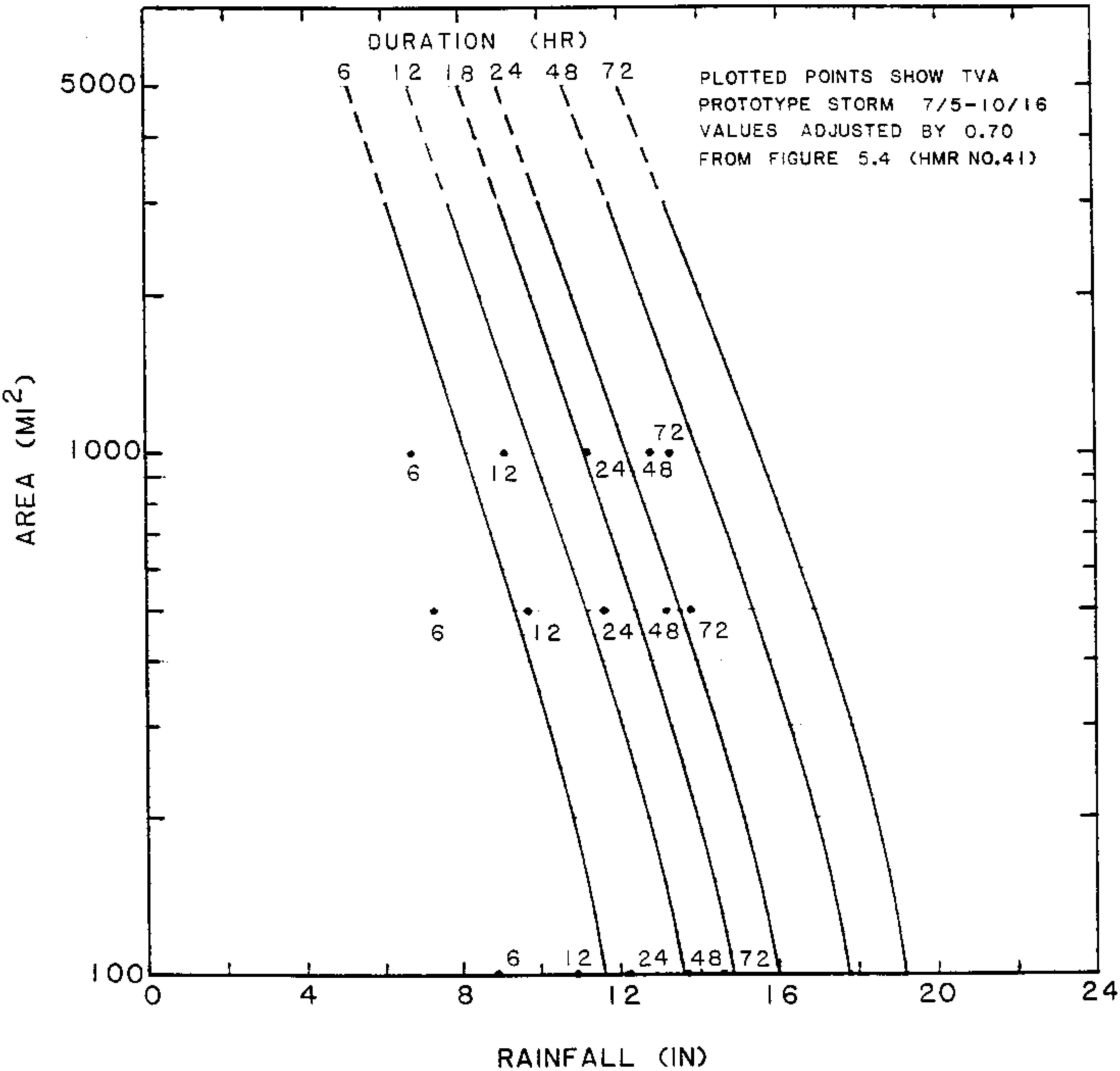


Figure 53.--Depth-area-duration curves for TVA precipitation at Knoxville Airport. Curves extrapolated from 3,000 to 5,000 mi^2.

influence of the Appalachian chain across the Tennessee Valley region. The orientation of the isohyets agrees fairly well with that of the generalized PMP percentile lines of figure 54. Comparison of figures 56 and 57 provide one measure of the generalized orographic effect in a particular basin.

For 18 specific basins in the eastern portion of the Tennessee River watershed, ratios between the basin-average mean annual precipitation and the basin-average mean annual "nonorographic" precipitation were computed (see table 4-2, items 4, 5, and 6 of HMR No. 45.) These ratios are one measure of the generalized orographic effect in a basin related to the distribution of primary upslopes,

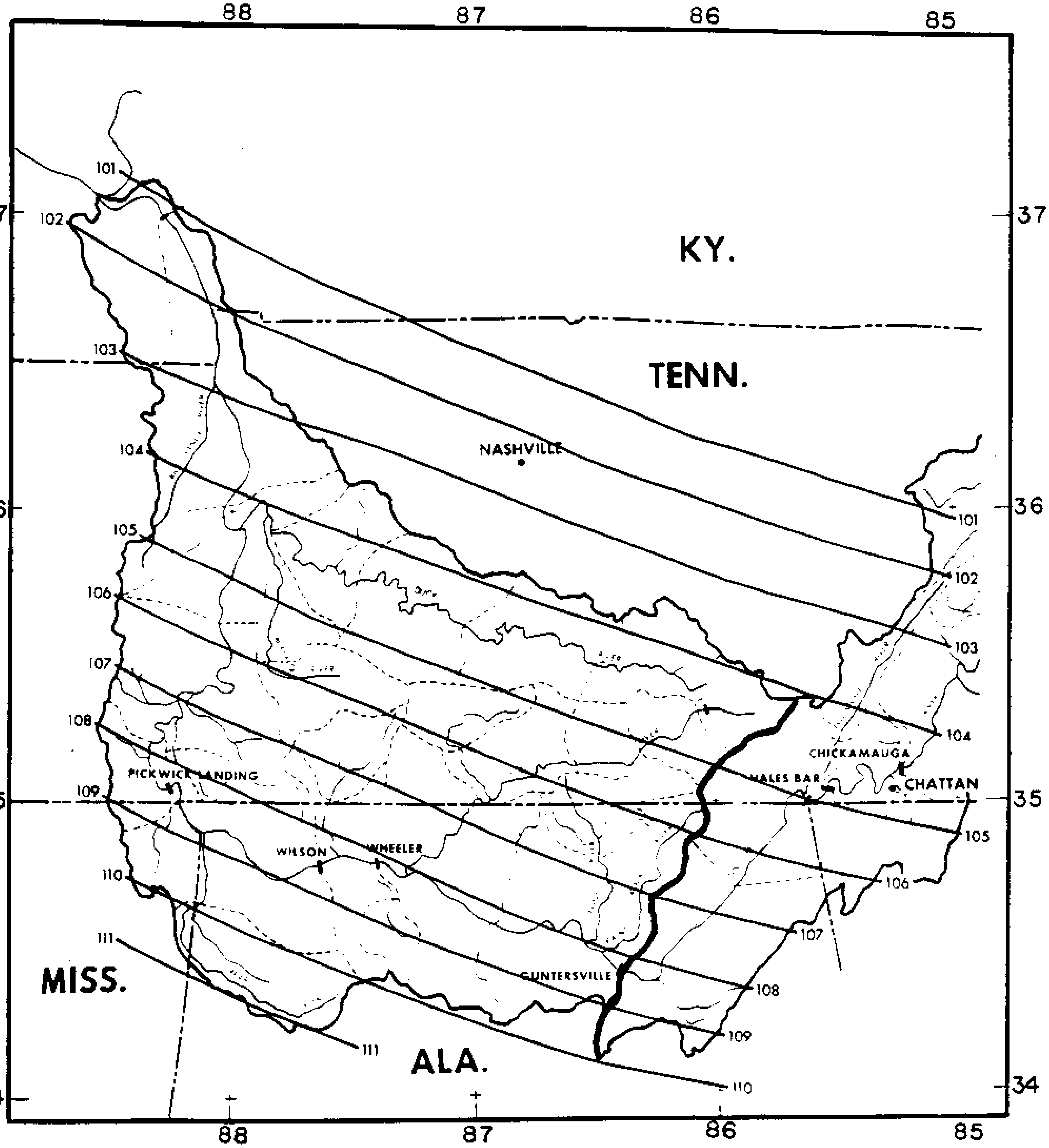


Figure 54.--24-hr 1,000-mi^2 PMP and TVA precipitation percentiles of Knoxville Airport for the western portion of Tennessee River watershed (note overlap of eastern region in fig. 55).

secondary upslopes, and sheltered areas within the basin (refer to sect. 2.2.4 for the definition of primary and secondary upslopes and sheltered areas, and to figure 14 for the distribution of these topographic features in the eastern part of the watershed). In other words, the variation of the ratios between average mean annual precipitation and average mean annual nonorographic precipitation over the eastern part of the watershed is related to the distribution of these three types of topographic features.

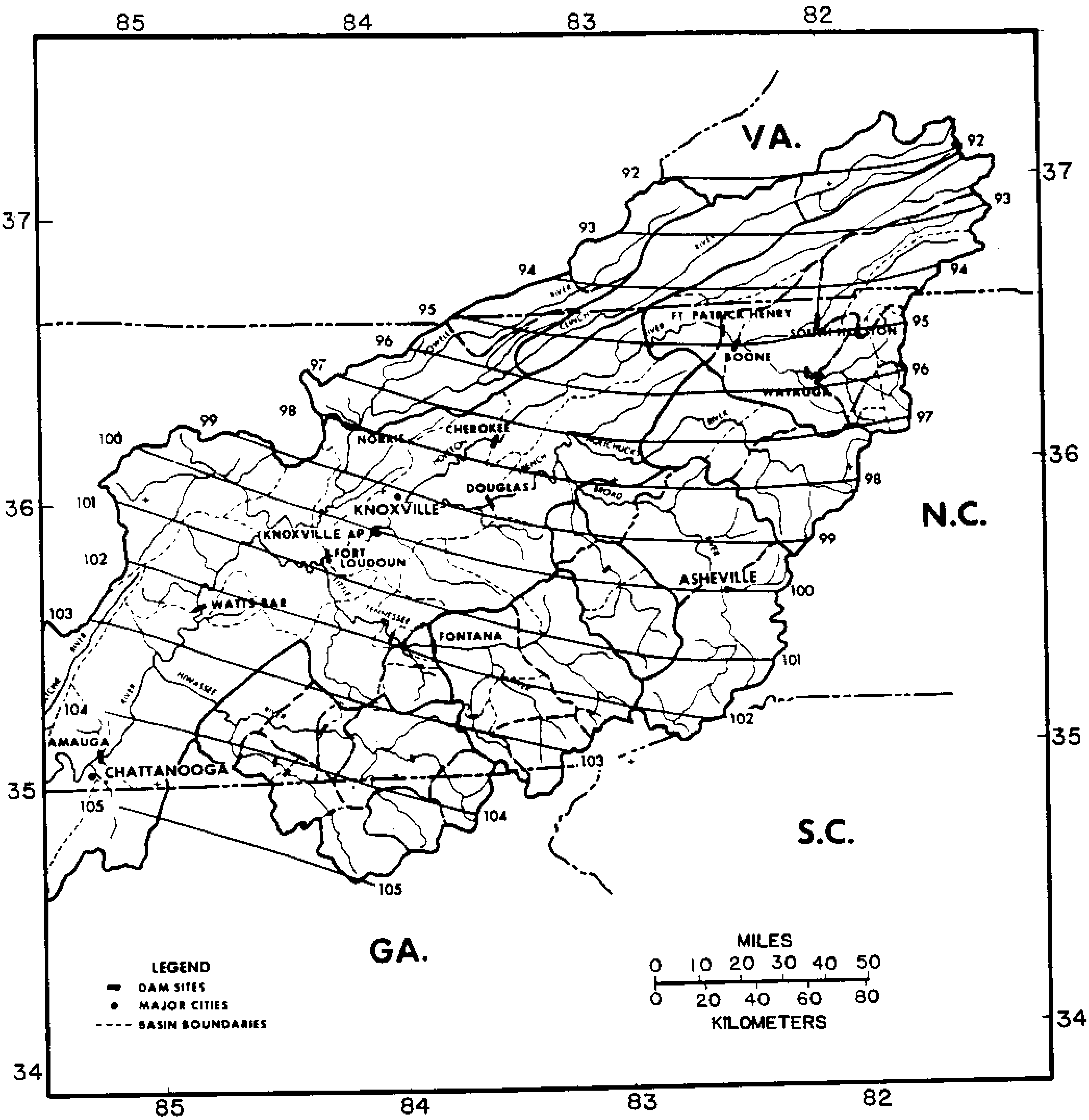
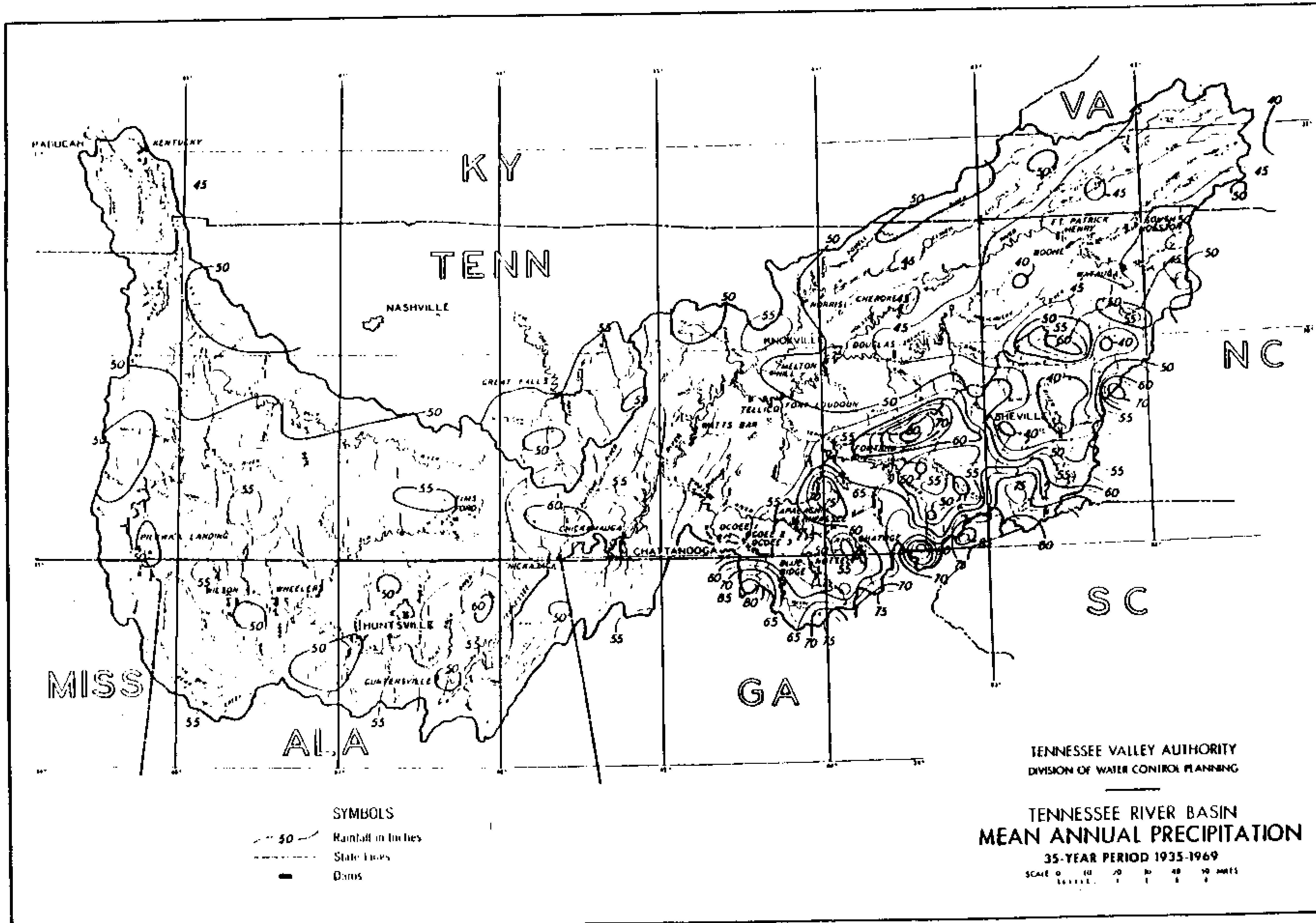


Figure 55.--24-hr 1,000-mi^2 PMP and TVA precipitation percentiles of Knoxville Airport for the eastern portion of Tennessee River watershed.

In order to develop a procedure for estimating the broadscale orographic factor (BOF) for each of the 18 basins (shown in fig. 100) for which estimated orographic ratios were given in table 4-2, item 7, of HMR No. 45, percentages of primary upslopes, secondary upslopes, and sheltered areas in the basins were computed. These respective percentages were then related via a regression analysis to the estimated ratios. The regression analysis indicated a correlation of 0.98 (standard error of estimate of 0.03) between the percentages and ratios. The regression analysis also gave "least squares" coefficients for relating the BOF and the percentage of primary upslopes, secondary upslopes, and sheltered areas. This is shown in equation form:



igure 56.--Mean annual precipitation (in.) for the entire Tennessee River watershed.

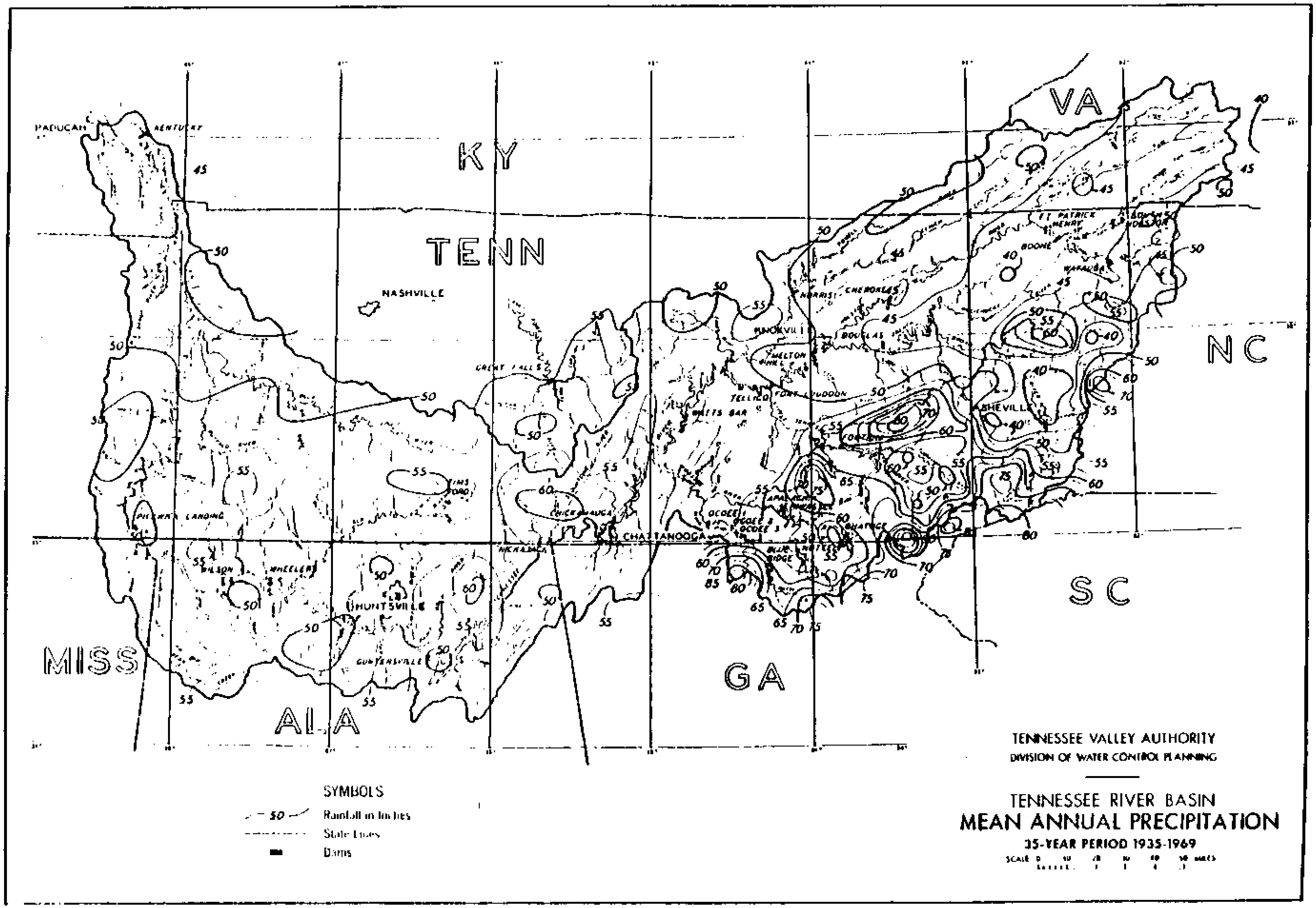


Figure 56.--Mean annual precipitation (in.) for the entire Tennessee River watershed.

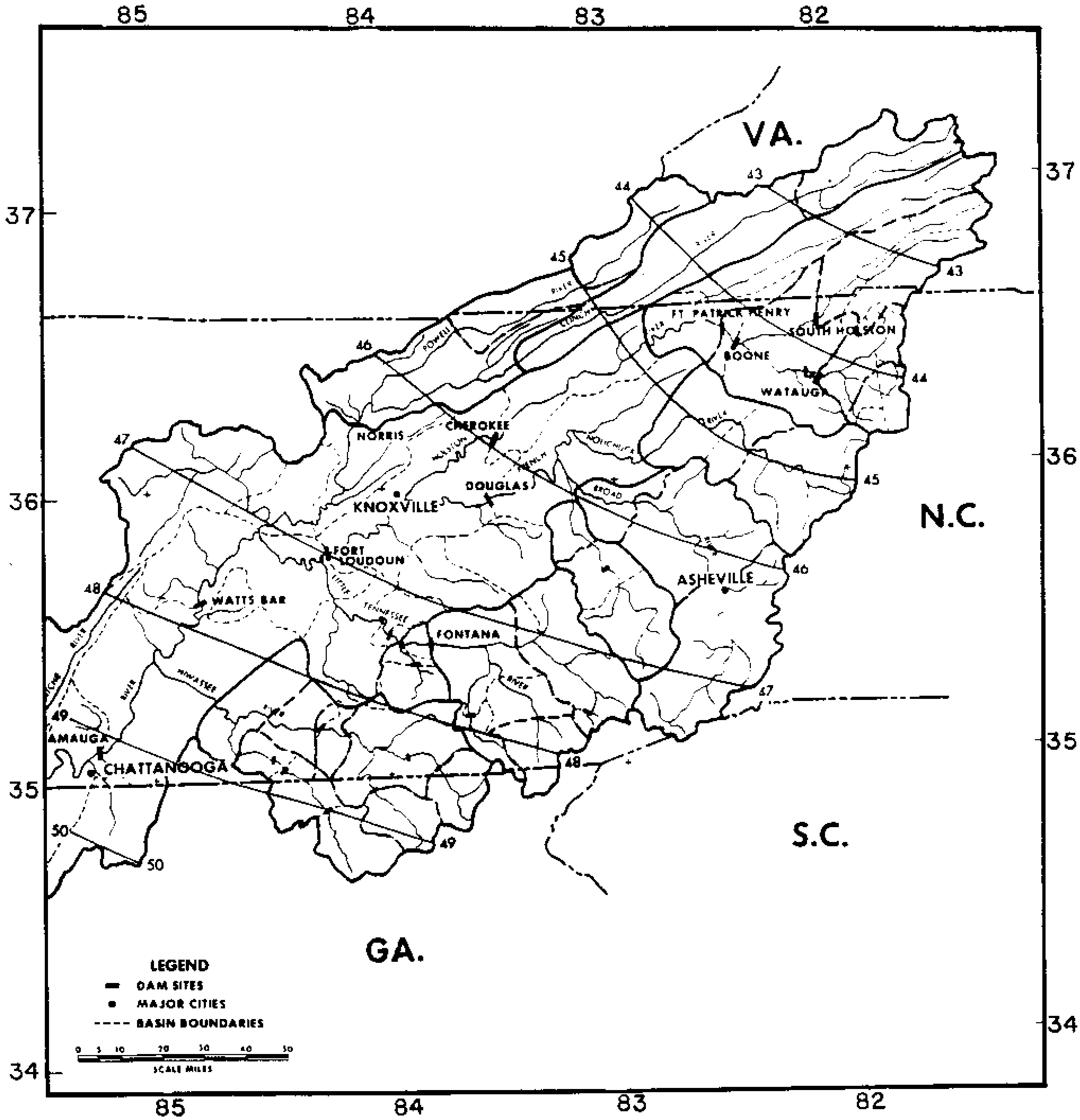


Figure 57.--Nonorographic component of the mean annual precipitation (in.) for the eastern Tennessee River watershed.

$$\frac{\text{Average mean annual precipitation}}{\text{Average mean annual "nonorographic" precipitation}} = \text{BOF} = .55 \text{ X } (\text{\% primary upslopes}) + .10 \text{ X } (\text{\% secondary upslopes}) + .05 \text{ X } (\text{\% sheltered areas})$$

The final number should be rounded to the nearest 0.05 to give the BOF, which will be used in evaluating the total PMP in chapter 5.

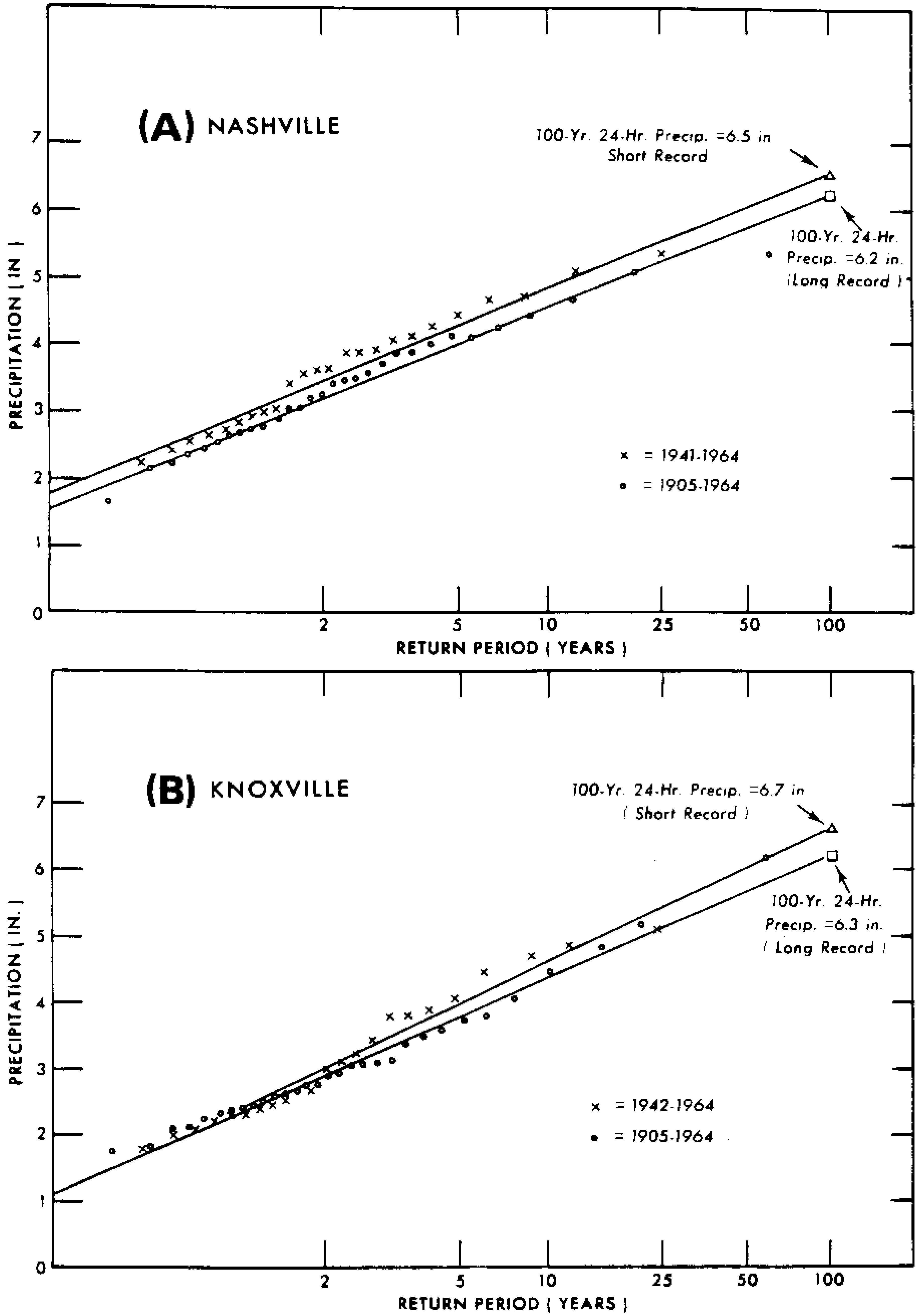


Figure 58.--Rainfall-frequency curves for (A) Nashville and (B) Knoxville, TN.

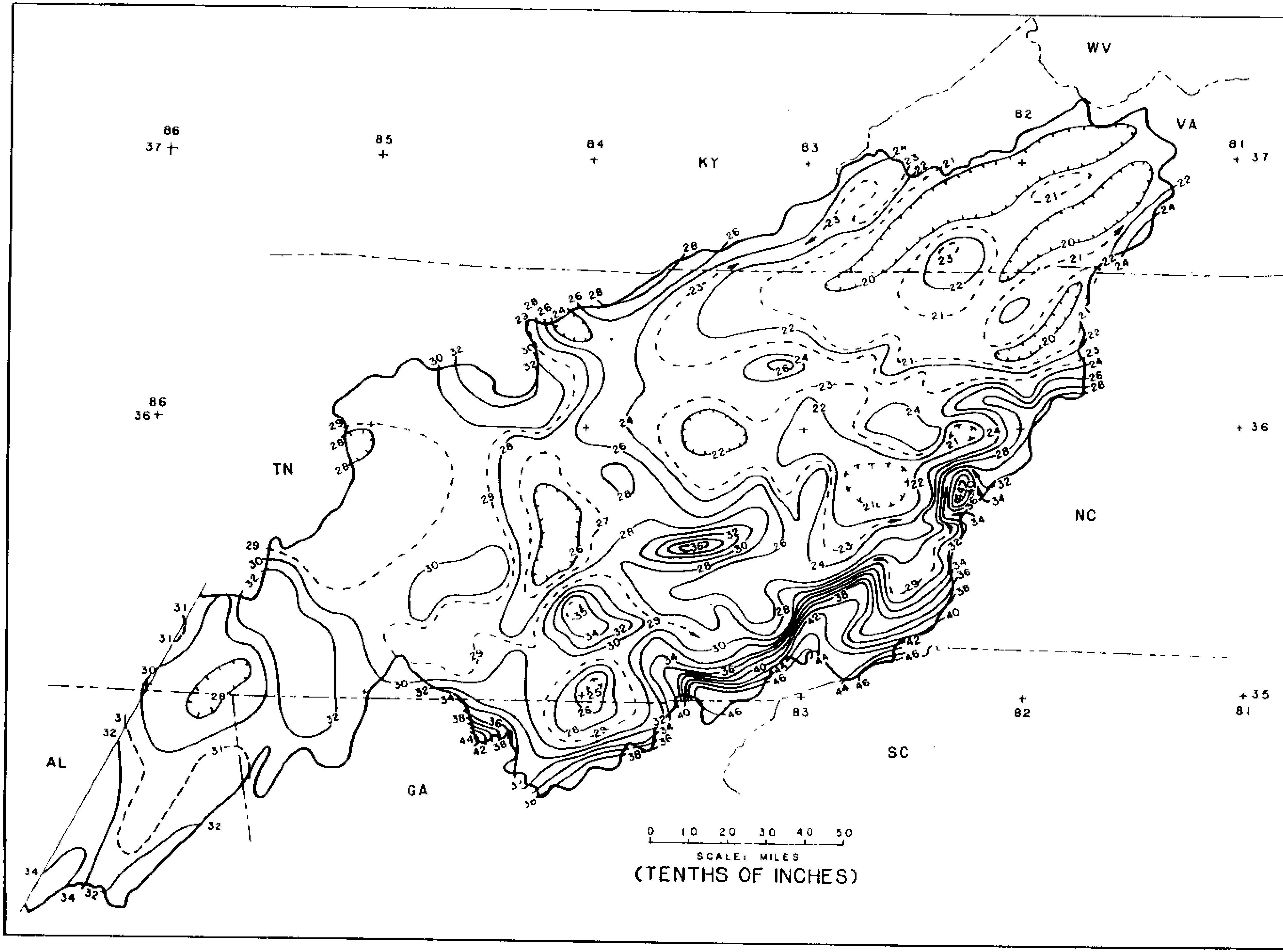


Figure 59.—2-yr 24-hr precipitation (in.) analysis - eastern Tennessee River watershed. Note that all values have been multiplied by 10.

3.4.2 2-yr 24-hr Precipitation Charts

To derive a 2-yr 24-hr precipitation chart, a frequency analysis was made of the annual maximum 24-hr rains for almost 600 stations in and near the Tennessee Basin with 15 yr or more of record as of 1980. Figure 58 shows that a 15-yr record tends to yield results not greatly different from those from a 60-yr record. An analysis of the 2-yr 24-hr values in the eastern portion of the basin is shown in figure 59.

The 2-yr 24-hr analysis shown here was expanded from the analysis drawn in HMR No. 45 (fig. 3.18) to include all of the stippled region of HMR No. 51 (roughly equivalent to the eastern portion of the region). This was done by including in the analysis additional station data from Technical Paper No. 29 (1957) and other data currently available since the publication of Technical Paper No. 29. While most of the 2-hr 24-hr data is derived from the same time period, the minimum period of record for use in the analysis was 15 yr.

The analysis shown in figure 59 will be used in computing the areal distribution of the PMP and TVA precipitation for basins in the eastern portion of the watershed (sect. 5.3.3.2).

3.4.3 Extreme Monthly Rains in Subbasins

Monthly precipitation averages over subbasins, published in "Precipitation in the Tennessee Valley" were also used for evaluating orographic effects. Subbasins with strongest orographic effects, as indicated by a total orographic adjustment factor (see table 21 in chapter 6) will tend to show highest monthly averages.

Several of the storms producing significant rainfall amounts in the Tennessee River watershed and discussed in the text occurred between 1955 and 1965 (see for example sections 2.1.2 and 3.2.3). Therefore, it was arbitrarily decided to use the 11-yr period 1955-1965 as a means of showing variation of highest monthly precipitation over subbasins in the eastern portion of the watershed. Figure 60 depicts for the eastern portion of the Tennessee River watershed the average of the three highest monthly precipitation values during the 11-yr period; the months contributing these values are listed in table 10*. In particular, the October 1964 storm is emphasized by underlining. This is because of the significant heavy rains which penetrated portions of the watershed during this month (see sect. 3.2.3 for more discussion of the storms which produced large amounts of precipitation). The highest individual monthly values are shown in figure 62 with the dominance of certain stormy months in contributing these values over certain areas indicated by various hatchings.

3.4.4 Small-Basin PMP

Another indicator of orographic influence, which to a certain extent makes use of other indicators, is the 6-hr 1-mi^2 PMP (figs. 22 and 23) vs. the "smooth" value that would be calculated at the position in the absence of terrain

*TVA zones indicated in the left of table 10 are shown in figure 61.

Table 10.--Dates of highest monthly precipitation over mountainous eastern zones (1955-1965)

TVA* Zone	Drainage	Highest	2nd Highest	3rd Highest
40	Hiwassee	Sept. 1957	July 1963	July 1958
41	Ocoee	July 1958	Sept. 1957	Oct. 1964
46	Toccoa	July 1958	Oct. 1964	June 1961
48	Hiwassee	July 1958	Aug. 1964	Aug. 1960
49	Hiwassee	July 1958	Aug. 1960	July 1963
52	Nottely	Oct. 1964	July 1958	June 1963
53A	Hiwassee	July 1958	Oct. 1964	Aug. 1960
54A	Hiwassee	Oct. 1964	Oct. 1959	July 1958
55	Valley	July 1958	July 1963	June 1957
62	Clinch	Sept. 1957	June 1960	July 1965
63	Powell	Sept. 1957	July 1956	June 1957
65	Clinch	Sept. 1957	July 1956	June 1958
67	Tennessee	Sept. 1957	July 1963	July 1958
69	Little Tennessee	July 1963	June 1957	July 1958
70	Little Tennessee	Aug. 1964	July 1963	June 1957
71	Cheoah	July 1963	June 1957	July 1958
72A	Little Tennessee	Aug. 1964	July 1963	July 1958
73	Tuckasegee	July 1958	Aug. 1964	Aug. 1960
74	Tuckasegee	Oct. 1964	Oct. 1959	Aug. 1964
75	Little Tennessee	Oct. 1964	July 1958	Oct. 1959
78	Nantahala	July 1958	Oct. 1964	Oct. 1959
84	French Broad	Aug. 1984	July 1956	June 1957
87	Holston	July 1958	July 1956	Oct. 1959
88	Holston	Sept. 1957	July 1958	June 1957
89	Holston	June 1957	July 1956	July 1958
92	Holston	July 1958	July 1956	Aug. 1957
93	Watauga	July 1956	Aug. 1961	June 1957
99	French Broad	Aug. 1964	July 1958	June 1957
101	Pigeon	Aug. 1964	Oct. 1964	July 1958
105	Pigeon	Sept. 1959	Sept. 1957	Oct. 1964
106	French Broad	Aug. 1964	July 1956	June 1957
110	French Broad	Aug. 1961	Oct. 1964	Sept. 1959
114	French Broad	Aug. 1961	Oct. 1964	Sept. 1959
117	French Broad	Aug. 1961	Oct. 1964	June 1957
120	Nolichucky	July 1956	Aug. 1964	July 1965
121	Nolichucky	Aug. 1961	June 1957	Sept. 1957

*TVA zones shown in figure 61.

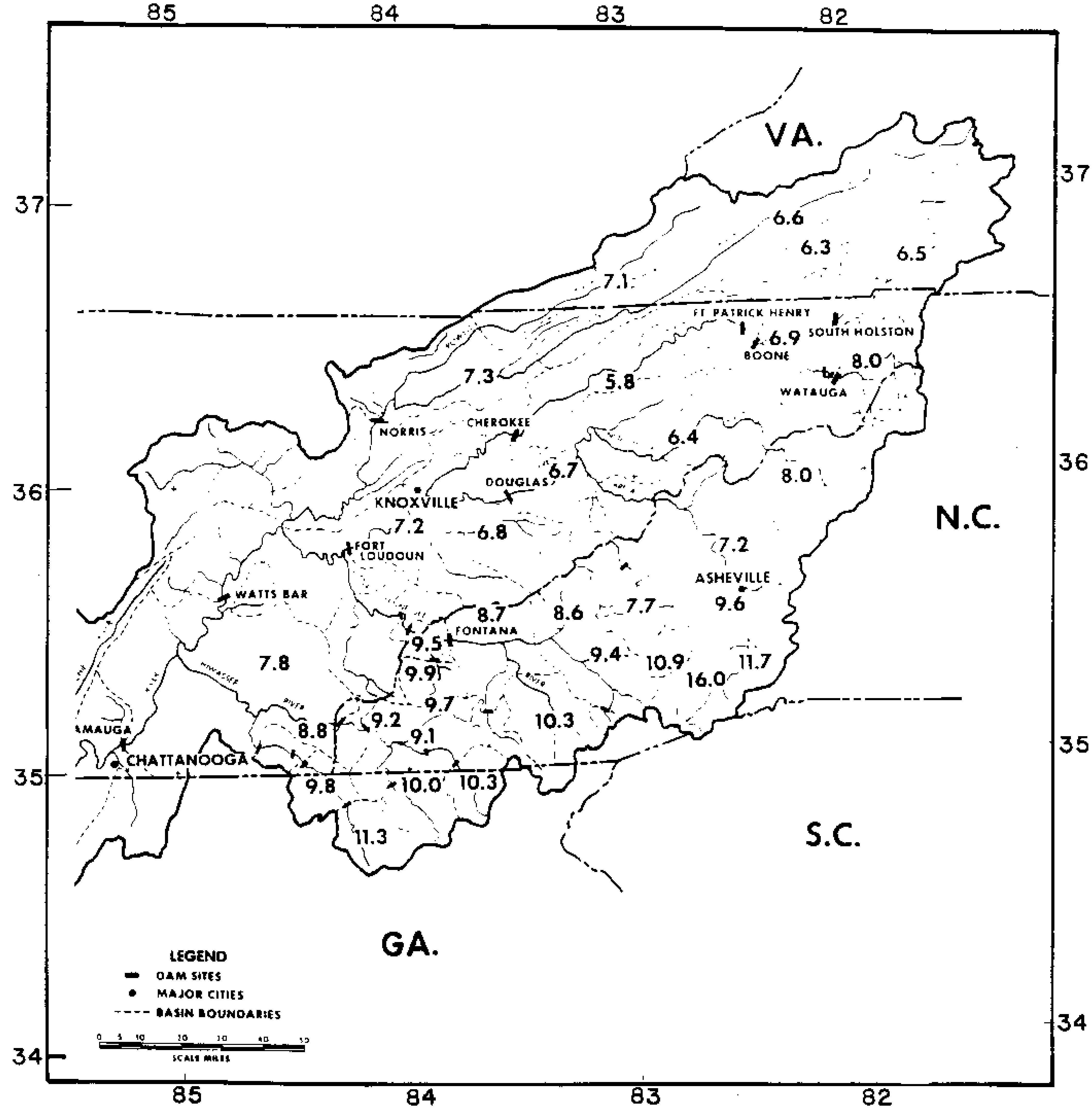


Figure 60.--Average of highest three months (table 10) of subbasin precipitation (in.) applicable to the overall critical wind direction.

features. This is used as a specific index relation in the generalized procedure to be described in section 5.4.3.2.

3.4.5 Optimum Wind Direction

Over a small basin--a few ten's of square miles -- it is presumed that the wind direction most favorable for unobstructed inflow of moist air and accentuation of lift by ground slope prevails during the PMP or TVA storm. In larger basins, the optimum direction for precipitation may differ from one portion of the basin to

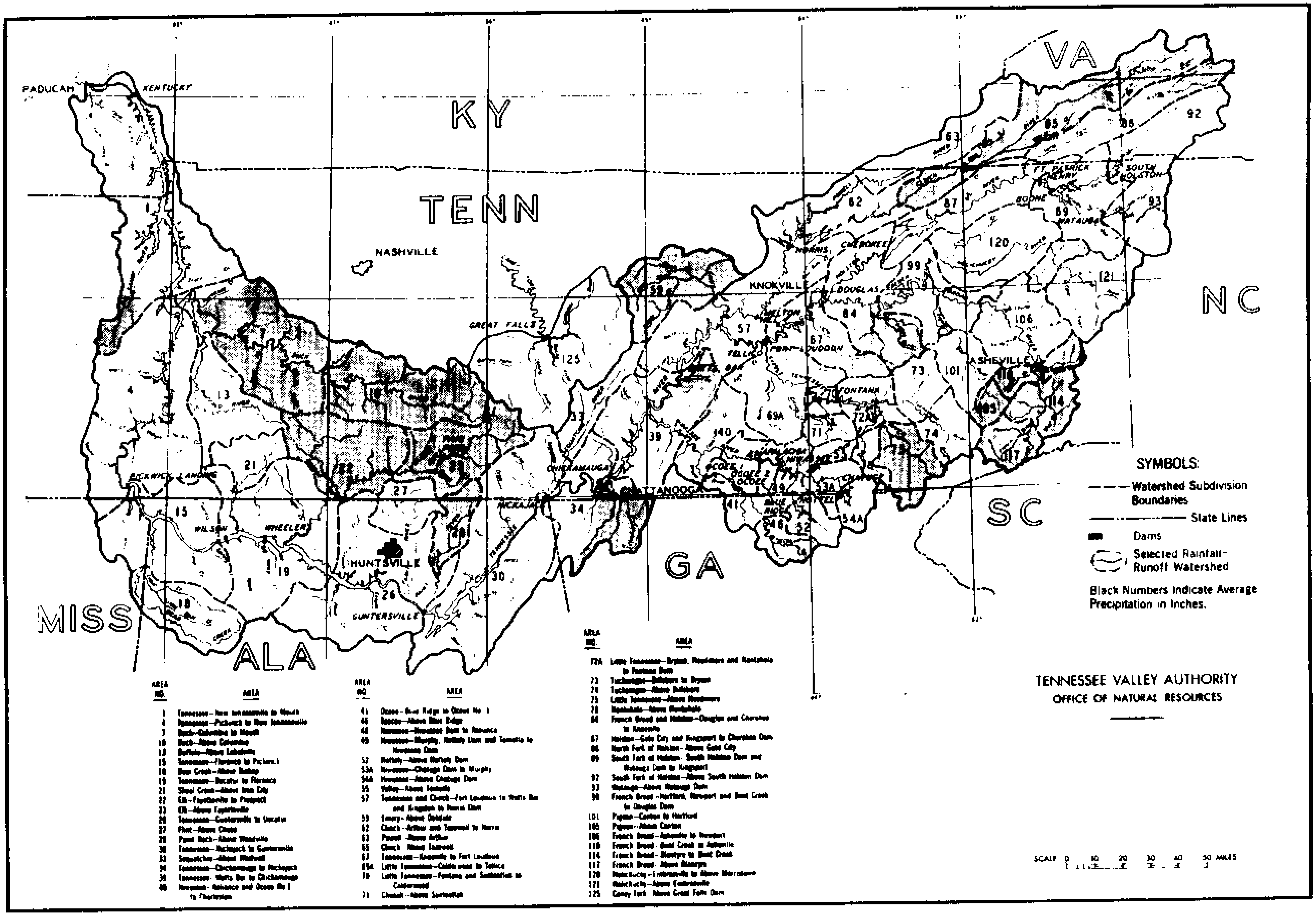


Figure 61.--TVA zones.

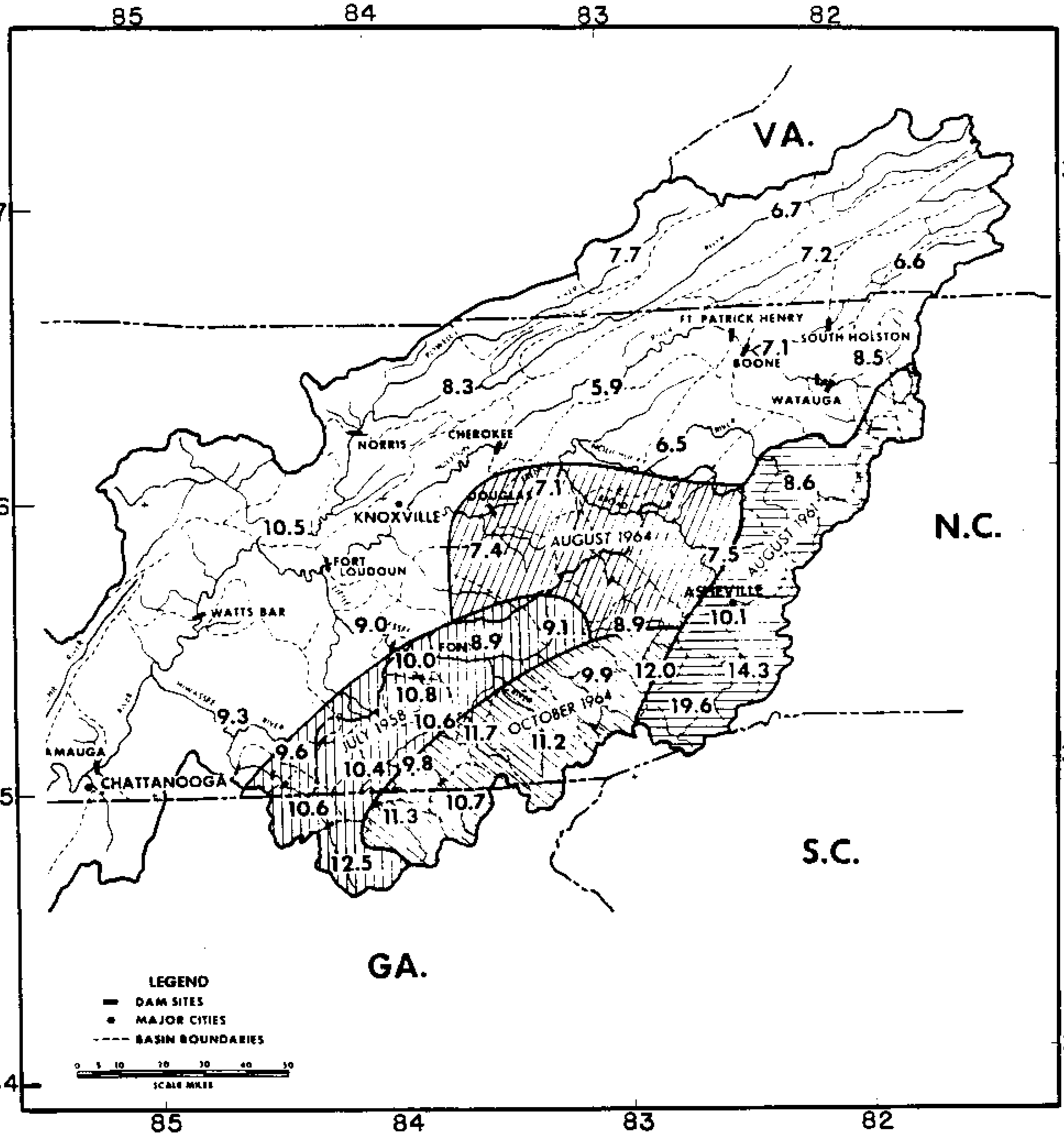


Figure 62.—Highest monthly (table 10) subbasin amount (in.). Hatched areas show limits of control by specific storms.

another because of varying orientation of principal slopes. The wind direction most critical for the basin as a whole is defined as the direction that is optimum over the largest fraction of the basin. A procedure is applied whereby the terrain intensification factor is related to the fraction of the basin for the optimum wind direction. Figure 63 shows the optimum moisture inflow direction for the mountainous eastern Tennessee River basins as either of southeast, south, southwest, or west. The figure was developed with the use of observed wind and precipitation data in each subbasin. Storms of significant magnitude, such as the September 28–October 4, 1964 storm described in section 3.2.3, were used in developing figure 63. The directions shown for each subbasin in figure 63 were derived by determining which wind direction, on the average, produced significant amounts of precipitation in the subbasin. In other

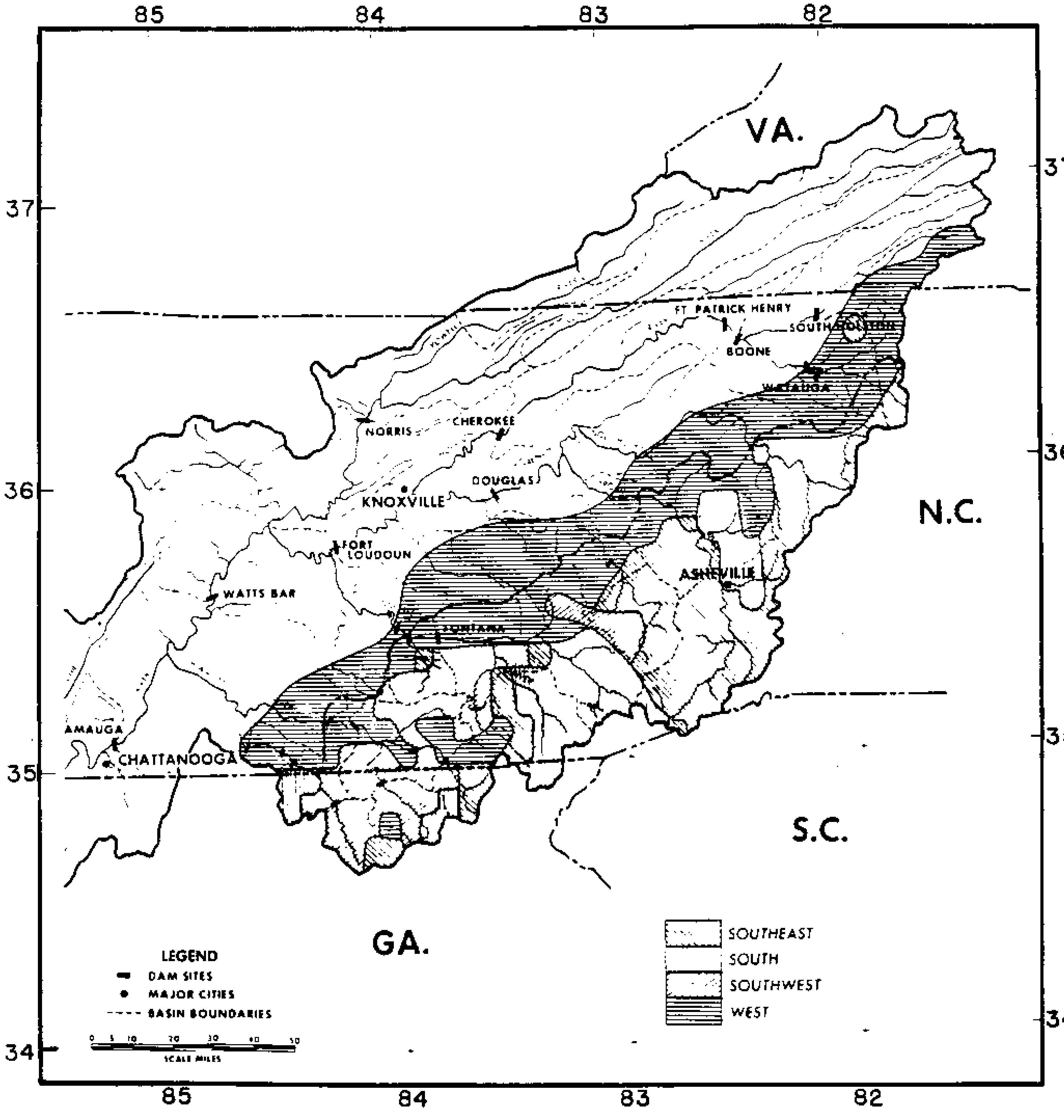


Figure 63.--Areas controlled by specific "optimum" wind directions.

words, the wind direction conducive to supplying an "optimum" amount of moisture to the subbasin was selected in figure 63. In applications, it is necessary to determine the largest percentage of the total basin covered by one of these directions. Using this percentage, the optimum wind adjustment factor is then determined from figure 64. Figure 64 was the result of empirical adjustments needed in making specific basin estimates in the region. To derive the relationship, specific adjustments were determined for subbasins 1 through 15 listed in table 22 and shown in figure 100. The specific estimates were obtained by looking at observed values of heavy precipitation in each subbasin. A subjective analysis was made to determine the amount of orographic influence on

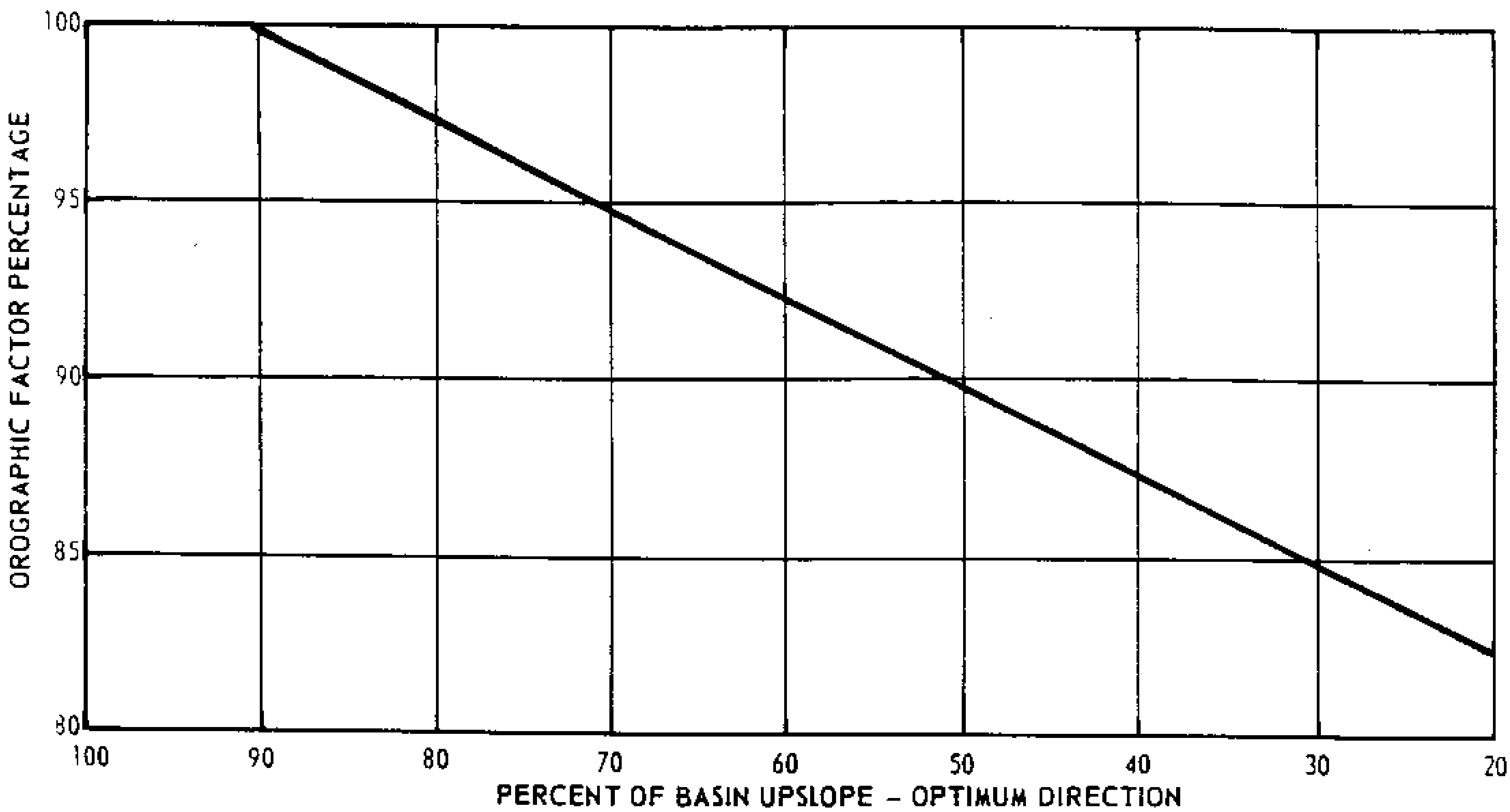


Figure 64.--Orographic wind adjustment chart.

total rainfall in each case. In addition, the percentage of the subbasin with a common wind direction was determined. These values were plotted on a graph similar to figure 64 and a line of "best fit" was established which is the line shown in figure 64.

3.5 Terrain Adjustment Methods

3.5.1 Introduction

As described in section 3.3.1 and 3.3.3, nonorographic PMP for area sizes between 100 and 3,000 mi^2 are obtained by multiplying a Knoxville, TN PMP value (fig. 52) for the selected area size by a geographic variation factor (figs. 54 and 55). In order to determine the total PMP, a terrain stimulation factor (TSF) must also be applied. This factor is related to the geographic location of the basin and its area size. In the mountainous east, the TSF must be modified by a sheltering effect and by an optimum wind adjustment before combining with the broadscale orographic factor (BOF) to develop a total adjustment factor (TAF). These adjustments are described in section 3.5.2 for the entire Tennessee River Valley, except the mountainous east. The adjustments for the mountainous east are described in section 3.5.3.

3.5.2 Terrain Stimulation Factor (TSF) for the Tennessee River Valley

The nonorographic PMP developed in section 3.3.1 does not consider the effect of terrain stimulation on convective cells and/or thunderstorms in general storms. In the small-basin procedure (chap. 2) this terrain stimulation was accounted for by development of separate depth-duration curves for "smooth",

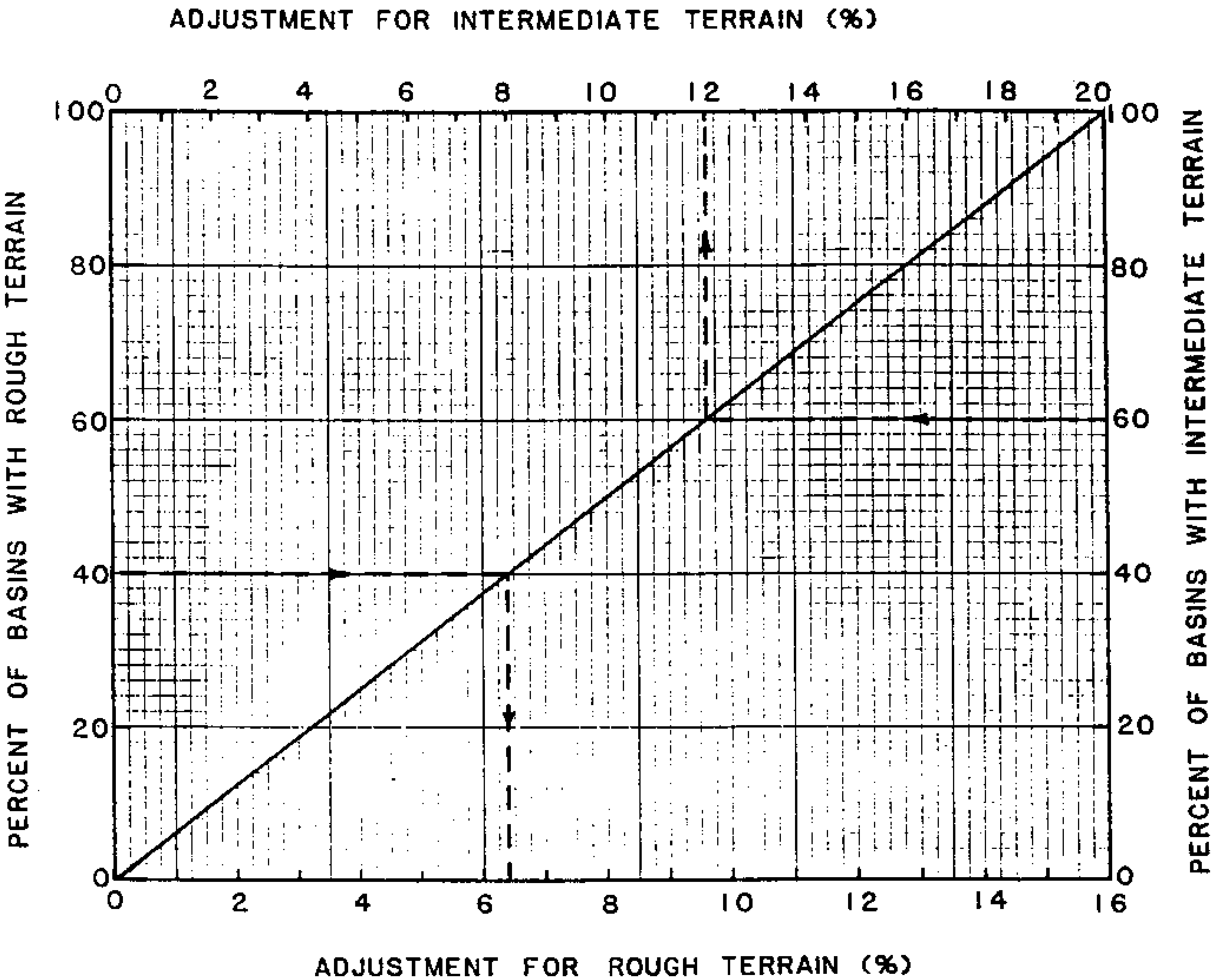


Figure 65.--Adjustments to large-area basins for terrain roughness valid for 100-mi^2 areas.

"intermediate", and "rough" terrain. The adjustment in the large-basin procedure for this terrain stimulation effect uses these same criteria.

The adjustments to be applied to large-basin estimates for terrain stimulation effects are given in figures 65 and 66. These figures were developed empirically in the Addendum to HMR No. 45 to account for differences obtained at the interface ($100\ mi^2$) when using either the small-basin or large-basin procedure. Modifications were made to figure 66 because of the changes made to figure 16 in this report.

The logic of applying these adjustments is that a roughness factor that causes terrain stimulation (from "fixing" and "triggering" of thunderstorm activity over small basins) is applicable in a modified form (decreasing effect) for basins

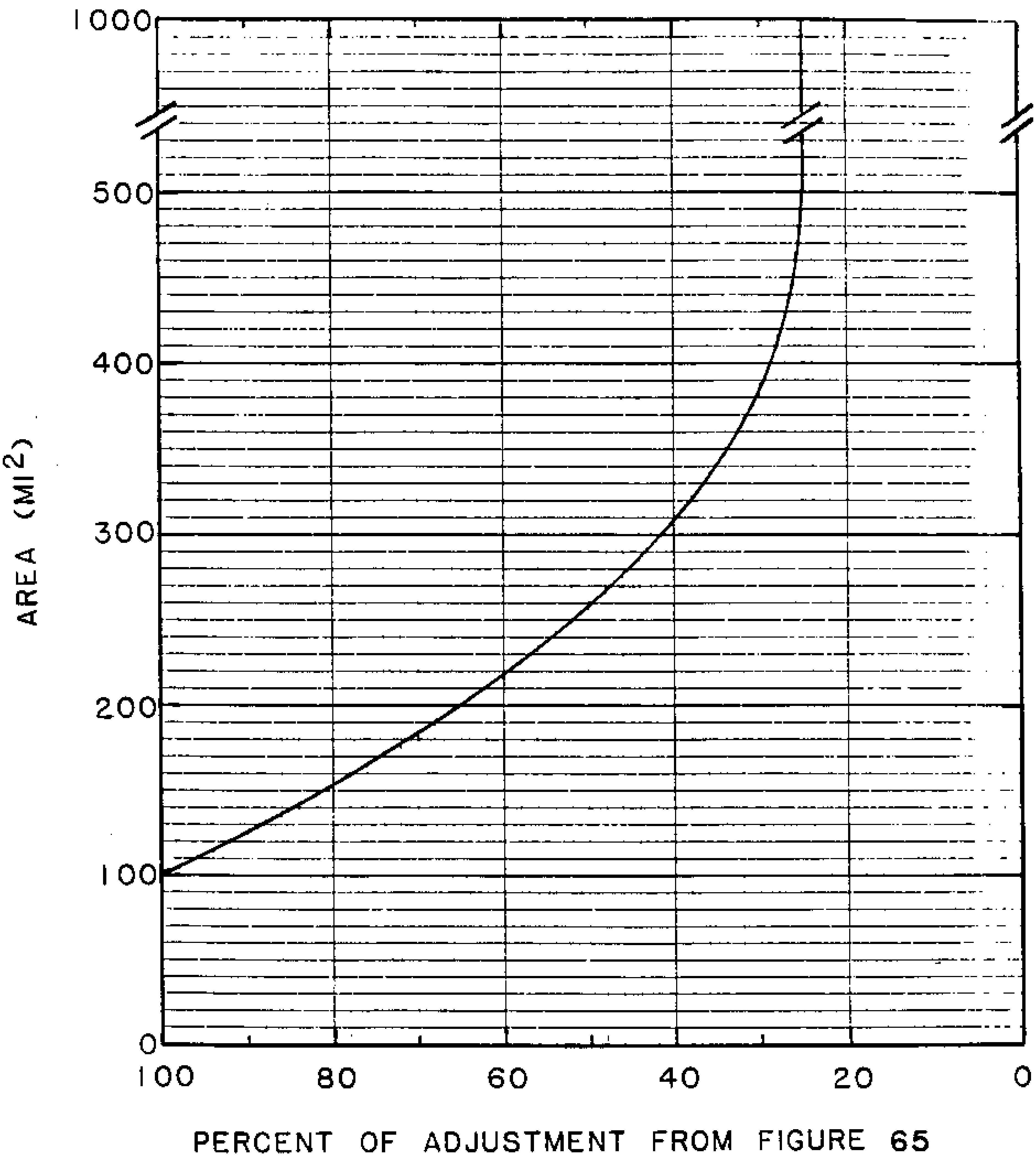


Figure 66.--Variation of terrain roughness adjustment (fig. 65) with basin size.

larger than 100 mi^2. However, it is not realistic to assume that all-rough areas will be effective in promoting thunderstorm fixing and triggering. The importance of thunderstorm rainfall within the total precipitation volume decreases with increasing area size. The adopted decrease in the stimulation effects associated with thunderstorm rainfall with increasing area size, shown in figure 66, is applied to the values determined from figure 65. One reads the areal adjustment from figure 66 that is applied to the terrain adjustment determined from figure 65 for the basin under consideration. Adjustments for basins greater than 500 mi^2 remain constant at 25 percent of the adjustment determined in figure 65 for 100 mi^2. As an example, consider an all rough

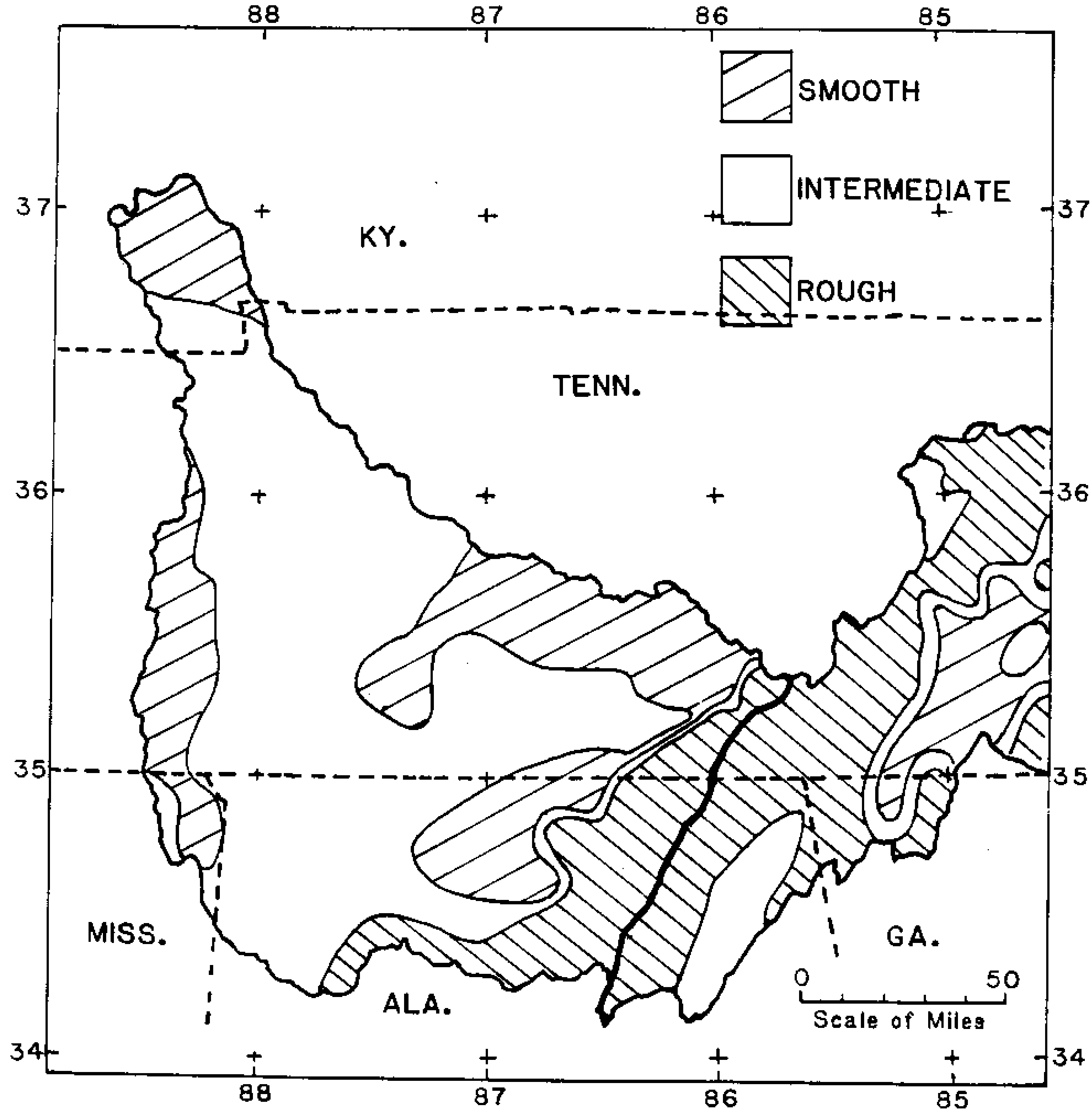


Figure 67.—Distribution of terrain, western Tennessee River watershed. (Note the overlap of the eastern region shown on fig. 68.)

1,000-mi^2 basin. The combined adjustment amounts to an increase of 4 percent (i.e., 16 percent from fig. 65 times the 25 percent from fig. 66).

To use the adjustments in figures 65 and 66 for all basins of 100 mi^2 or more, it is first necessary to determine those parts of the basin that are covered by rough and intermediate terrain (smooth is not considered here). These classifications are shown on figures 67 and 68. To apply the adjustment to a drainage entirely in one region, determine the percent of the basin in each of the two terrain categories (rough and intermediate) and compute the adjustments based on these percents (fig. 65) and the modification of the total adjustment for area size (fig. 66). As an example, suppose a 200-mi^2 basin in the eastern half of the Tennessee River Watershed (non-mountainous east region) has 20

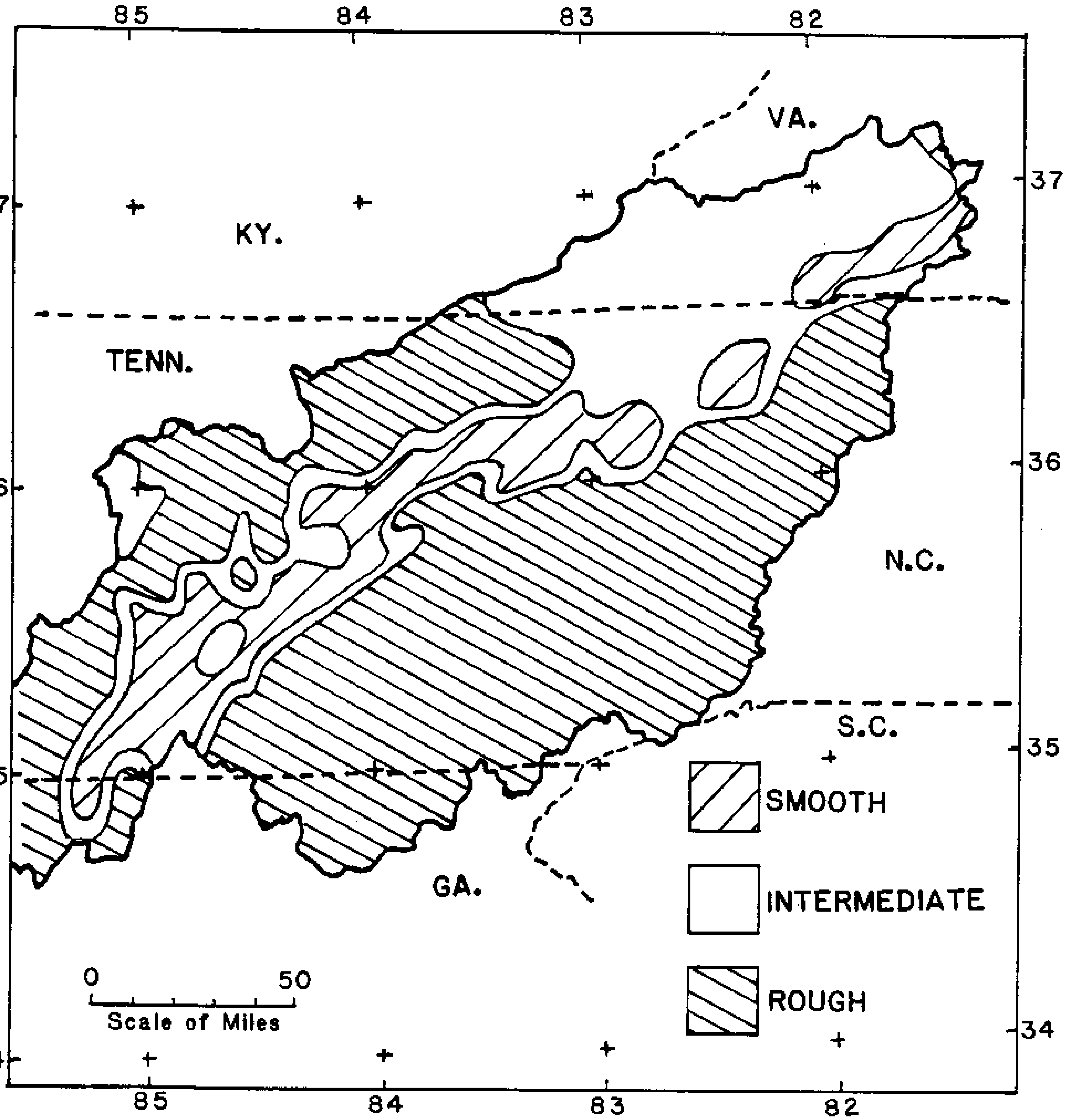


Figure 68.--Distribution of terrain, eastern Tennessee River watershed.

percent of its area classified rough and 50 percent intermediate (the 30 percent smooth terrain has no adjustment). A combined adjustment is then obtained from figure 65, considering the percent of the basin in rough and intermediate terrain. In our example, the combined adjustment amounts to 13 percent (3 percent (fig. 65) for the 20 percent rough portion of the basin, plus an additional 10 percent (fig. 65) for the 50 percent intermediate portion of the basin. Therefore, the nonorographic basin PMP and TVA precipitation values are increased by a total of 13 percent for the "roughness" of the basin topography. This 13 percent would apply unadjusted if the basin were 100 mi^2. The reduction to this stimulation increase for basin size is obtained from figure 66. The 13 percent increase from figure 65 is multiplied by the 64 percent from figure 66 for the 200 mi^2 area of the basin. In our example, this would give a total increase of 8.3 percent for this example. Thus, the TSF for this basin would be 1.083.

3.5.3 Total Adjustment Factor (TAF) for the Mountainous East

In the mountainous east, in addition to the terrain stimulation effect discussed in section 3.5.2, it is necessary to consider the broadscale orographic factors (BOF). The combination of the TSF and BOF in this region is the total adjustment factor (TAF). However, it first must be recognized that the TSF in this region needs to be further modified from that given in section 3.5.2. These modifications are the result of sheltering effects and consideration for the optimum wind direction.

The need for these additional factors in determining the TSF can be better understood by reference to the small-basin 6-hr 1-mi^2 PMP map (fig. 23). In the mountainous east region of figure 23, note that although the entire region is classified as "rough," there are several areas where the 6-hr 1-mi^2 PMP is less than 37.4 in. (the threshold for rough classification). This is the result of sheltering effects of the terrain on thunderstorms. Therefore, before determining the TSF, it is necessary to first remove the effects of all-rough terrain from figure 23 in the mountainous east.

The next step is to determine the TSF as done in section 3.5.2, but modified by consideration of sheltering and optimum wind direction as discussed in section 3.4.5. Then, determine the BOF by evaluating the percent of the basin comprised of primary upslopes, secondary upslopes and sheltered areas discussed in section 3.4.1. Finally, the modified TSF and BOF are added to obtain the TAF.

This rather complex adjustment determination can best be clarified by an example. Suppose a 300-mi^2 basin centered at 35.85°N 83°W, in the mountainous east, has a 6-hr 1-mi^2 basin average PMP of 40.1 in (from fig. 23). Since the basins located in the mountainous east are all 100 percent rough, there is a small-basin terrain-roughness from figure 65 of 16 percent. Dividing the 40.1 in. by the factor 1.16 gives 34.6, which removes all of the thunderstorm-induced terrain effect at a basin size of 100 mi^2, so that the appropriate terrain stimulation adjustment for the size of the basin can now be determined as in section 3.5.2. Figure 66 is used to obtain the adjustment for the size of the basin, 300 mi^2. The adjustment is 42 percent of the total 16 percent (for the all-rough basin), or 6.72 percent. Multiplying the 34.6 by 1.0672 gives 36.9 in. This is the nonorographic TSF-adjusted PMP.

The next step is to evaluate the modification caused by the sheltering effect on the nonorographic 6-hr 1-mi^2 PMP (fig. 16). The smooth basin PMP for 6-hr 1-mi^2 of 34.4 in. (the smooth 6-hr 1-mi^2 value at the southern edge of the Tennessee River watershed, or the 0-percent correction line of figure 69) is obtained from figure 16. Determine the sheltering factor from figure 69 applicable to the basin.

For the basin in this example, figure 69 gives a sheltering effect of 6 percent which must be subtracted from 100 to obtain the sheltering factor, 94 percent, that is multiplied by 34.4 in.. This product is 32.3 in. By dividing the TSF-adjusted PMP of 36.9 in. by the smooth PMP adjusted for sheltering of 32.3 in., or 1.14, one obtains the percentage orographic increase applicable to the basin. Thus, the TSF gives a 14 percent increase in the 6-hr 1-mi^2 PMP related to fixing and triggering of thunderstorm activity.

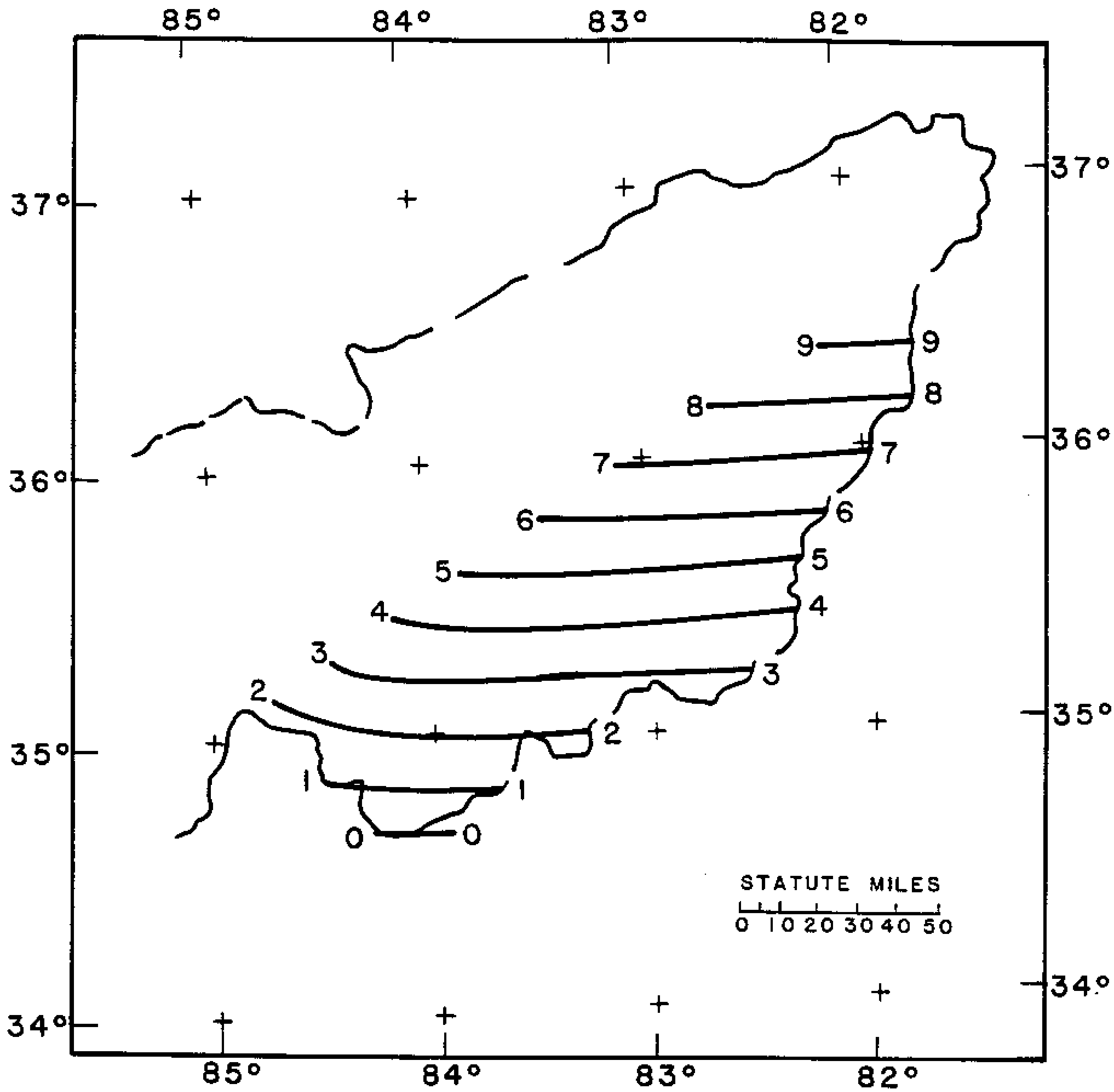


Figure 69.--Generalized adjustment for terrain sheltering in the eastern half of the Tennessee River drainage basin (percent reduction in PMP and TVA precipitation).

To adjust the TSF for optimum wind direction, enter figure 63 and determine the direction covering the greatest portion of the basin. For this example, 85 percent of the basin is covered by westerly winds. Enter figure 64 at 85 percent on the abscissa and read the adjustment factor of 98 percent. Multiply the TSF of 1.14 by 0.98 to get the final modified TSF of 1.12.

To determine the BOF, consider the percent of the basin covered by primary upslopes, secondary upslopes and sheltered areas in figure 14. If, in this example, these percentages are, respectively, 20, 40 and 40; then, using the factors given in section 3.4.1 of 0.55, 0.10, and 0.05, the BOF is (.20)(.55) + (.40)(.10) + (.40)(.05) = .11 + .04 + .02 = .17. The BOF is rounded to the nearest 5 percent, or 0.15.

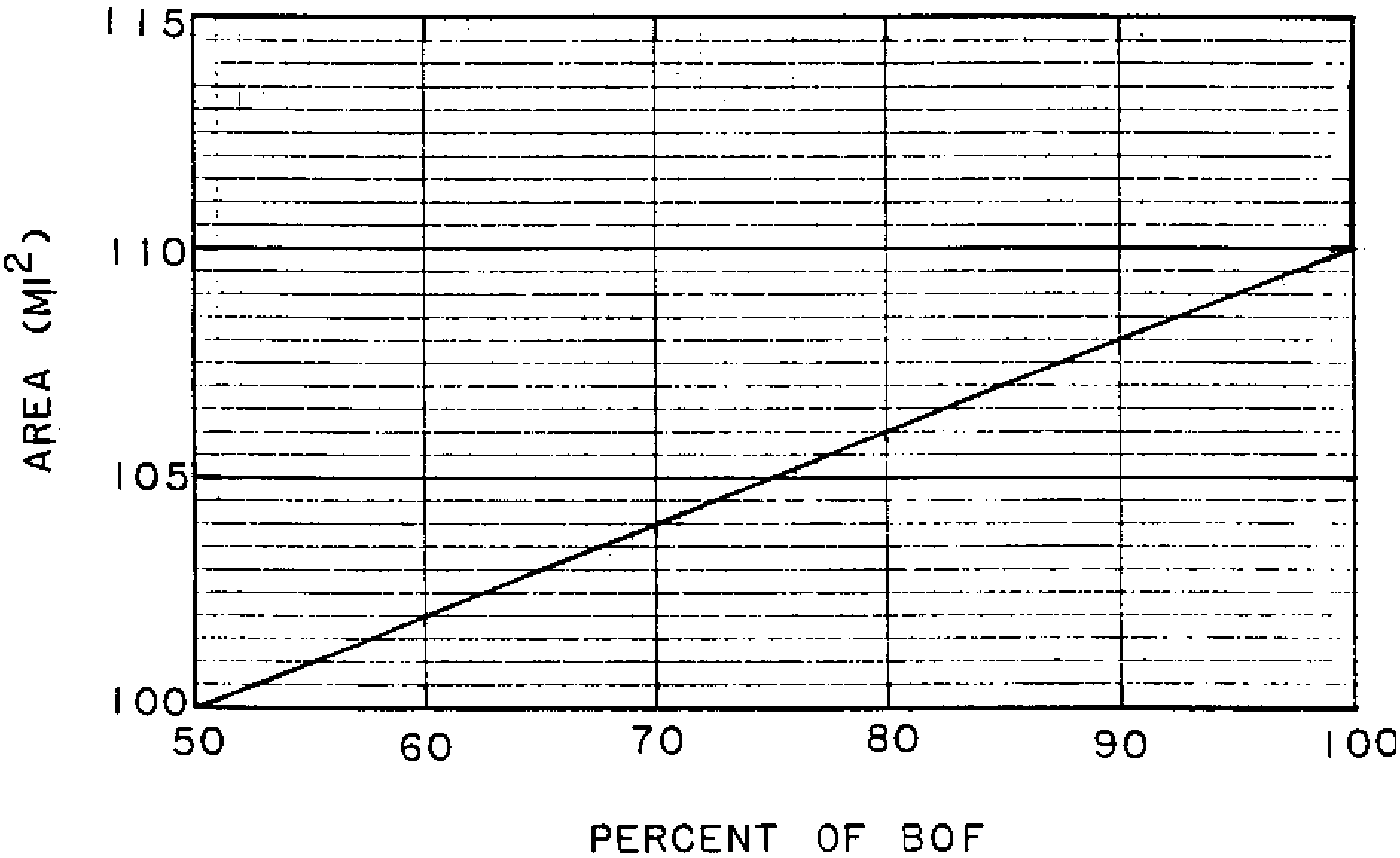


Figure 70.--Adjustment applied to broadscale orographic factor (BOF) for areas near interface between large- and small-basin procedures.

For this example, the TAF = TSF + BOF = 1.12 + .15 = 1.27 and rounds to 1.25. Additional examples of these factor determinations are given in chapter 5.

3.6 100-mi^2 Interface Differences

Application of the procedures described in sections 3.5.2 and 3.5.3 to develop PMP estimates for basins larger than 100 mi^2 has shown that, for basins close to 100 mi^2 in some regions, differences may be found between estimates developed from chapter 3 (large basin-procedure) and those from chapter 2 (small-basin procedure). Through a process of sample evaluation throughout the TVA region, it was noted that the differences occurred only in the mountainous east region for basins between 100 and 110 mi^2. Figure 70 has been developed to adjust the large basin factors applied to the various orographic classifications as depicted in figure 14 in the procedure (see sect. 5.4). The effects of figure 70 are primarily applicable to those drainages that are almost totally comprised of first upslopes in figure 14.

The application of the factors from figure 70 effectively reduces the observed differences at the interface area of 100 mi^2. However, because the small- and large-basin procedures are almost wholly independent, it is still likely that complete agreement will not occur between depth-duration estimates for areas in the vicinity of 100 mi^2. That is, for some computation, depth-area-duration relations developed by the small-basin procedure may give somewhat lower estimates at 100 mi^2 than estimates based on depth-area-duration relations using the large-basin procedure. At other times, the reverse is possible.

Since continuous depth-area-duration relations are needed for the areal distribution procedure discussed in section 4.3, the following recommendation is made. In such cases where discontinuous depth-area-duration relations occur at

100 mi^2, blend across this discontinuity with subjective smoothing. By this, it is meant to adjust whichever depth-area lines necessary to effect a smoothly varying depth-areal curve through areas affected. In general, it is anticipated that such smoothing can be limited to areas near 100 mi^2, but in some instances areal values up to 400 or 500 mi^2 may need to be adjusted. A demonstration of this recommendation is given in the example worked in section 5.5.2.

3.7 Summary

In drainages up to 3,000 mi^2, the primary rain producing storms in the Tennessee Valley are derived from combined decadent tropical storms and thunderstorms imbedded in general storms. The storm of September 28 to October 4, 1964 was a classic example of such a combined storm containing a large percentage of nonorographic rainfall. Features of such storms that are important to large rains in the region are:

1. High values of low-level moisture for the season of occurrence

2. Geographic fixing of repeating rain events

3. Thunderstorm involvement

This chapter presented a technique for determining the nonorographic component of PMP and TVA precipitation. The technique adjusts the depth-area-duration PMP or TVA precipitation data at Knoxville Airport, TN to the location of the drainage based on ratio maps (fig. 54 and 55).

The procedures used to develop the nonorographic precipitation do not adequately consider the effect of terrain roughness on the general storm. A terrain stimulation factor (TSF) based on the "rough" and "intermediate" terrain classifications is used to modify the nonorographic PMP and TVA precipitation. The TSF is first determined for an area of 100 mi^2 and then modified for the area size of the drainage.

In the mountainous eastern Tennessee Valley, the TSF must be further modified for orographic effects that are determined from consideration of five sets of indicators.

1. Mean annual nonorographic and orographic precipitation

2. 2-yr 24-hr precipitation

3. Highest monthly rains in subbasins

4. Small-basin PMP

5. Optimum wind directions

These indicators are used as guidance in modifying the TSF, based on a classification of slopes exposed to the optimum wind direction for a basin. The B.F. broadscale orographic factor is based on consideration of the proportion of the basin covered by primary and secondary upslopes and sheltered areas. The BOF is combined with a terrain stimulation factor to obtain the total adjustment factor (TAF), applied to the nonorographic computation of either PMP or TVA precipitation.

Finally, consideration is given to the situation where small differences arise between estimates at 100 mi^2 when derived from both the small-basin procedure and the procedure for basin areas of 100 to 3,000 mi^2. The recommended solution is to blend between the respective depth-area curves.

4. AREAL DISTRIBUTION OF PMP AND TVA PRECIPITATION

4.1 Introduction

HMR No. 45 (Schwarz and Helfert 1969) provided information on areal distribution of PMP and TVA precipitation and discussed the relative differences in application to basins in western and eastern TVA regions. More recently, HMR No. 52 (Hansen et al. 1982) provides a more comprehensive study of areal distribution for storm areas throughout the eastern United States. This study further developed and expanded the methodology provided by Schwarz and Helfert (1969). Of particular advantage from the HMR No. 52 studies was the work resulting in residual precipitation analysis. This feature essentially allows the user to evaluate the precipitation that falls outside the PMP storm area but concurrently with the PMP storm. Such information offers numerous benefits to hydrologic analyses.

A decision was made in the present study to use the HMR No. 52 procedures for areal distribution of storm-average depths of nonorographic PMP and TVA precipitation in the Tennessee Valley drainages. Application of these procedures in this report provides the technique for converting storm-centered information to basin-centered information. For convenience, the necessary steps and figures from HMR No. 52 required for making these computations are reproduced in this chapter. Reference should be made to HMR No. 52 for discussions concerning the development of the information provided in this chapter.

While the information in HMR No. 52 applies specifically to the concept of nonorographic PMP, the same concepts and applications will be used in this study regarding nonorographic TVA precipitation components. In addition, the conversion factors of 0.58, 0.55 and 0.53 developed in the small-basin procedure to obtain rough, intermediate and smooth TVA precipitation, respectively, from PMP values, will be applied in this chapter as well. Adoption of these conversions provided a first approximation technique for deriving the areal distribution of TVA precipitation. Specifically, if the areal distribution of TVA precipitation is required, first determine the incremental isohyetal labels for PMP. Then, apply the respective conversion factor according to whether the primary basin is mostly rough, intermediate, or smooth. Clarification of this procedure will be given in the examples provided in chapter 5.

The procedures and idealized isohyetal pattern in HMR No. 52 apply to nonorographic PMP storms only, and therefore can be used without modification for basin studies in the western portion of the Tennessee Valley (refer to fig. 1). However, in the eastern portion of the region, the pattern is modified by the effects of terrain, and section 4.3.2 discusses the methods developed for this study.

The following definitions are useful in considering the areal distribution of storm rainfalls. Refer to figure 71 for additional clarification:

PMP storm pattern The isohyetal pattern that encloses the PMP area plus the isohyets of residual precipitation outside the PMP portion of the pattern. The standard isohyetal pattern covering the basin and concurrent basins of interest is shown in figure 72.

PMP storm area The area of the PMP storm that provides the maximum volume of precipitation over the drainage being considered. In figure 71, the pattern of solid isohyets.

Residual precipitation The precipitation that falls outside the PMP storm area, regardless of the size of the drainage. Because of the irregular shape of the drainage, or because of the choice of a PMP pattern smaller in area than the area of the drainage, some of the residual precipitation can fall within the drainage. Thus, in many applications the maximum volume of precipitation in a drainage comes from both the PMP storm (the solid isohyets in fig. 71) and residual precipitation (the dashed isohyets in fig. 71).

Concurrent precipitation The precipitation that falls outside the drainage of interest. Concurrent precipitation can be composed of both PMP and residual precipitation. In figure 71, subdrainage B (unhatched) is a concurrent drainage to the drainage of interest (subdrainage A). Precipitation falling in subdrainage B is thus concurrent precipitation. Concurrent precipitation can be determined for any number of drainages surrounding the drainage of primary interest.

Isohyetal orientation The orientation (direction from north) of the major axis of the elliptical pattern of PMP. The term is used in this study also to define the orientation of precipitation patterns of major storms when approximated by elliptical patterns of best fit. To avoid the need for specifying dual orientations a rule has been devised in HMR No. 52 to identify orientations by directions between 135 and 315 degrees, only.

Storm-centered area-averaged PMP The values obtained from this report corresponding to the area of the PMP portion of the PMP storm pattern. In this report, all references to PMP estimates or to incremental PMP infer storm-area averaged PMP.

Drainage or Basin-averaged PMP After the PMP storm pattern has been distributed across a specific drainage and the computational procedure of this report applied, we obtain drainage-averaged PMP estimates. These values include that portion of the PMP storm pattern that occur over the drainage, both PMP and residual.

4.2 Isohyetal Pattern

4.2.1. Standard isohyetal pattern

Figure 72 shows the standard elliptical isohyetal pattern used in this study. The ratio of major to minor axis in this pattern is 2.5 to 1 in keeping with the results of a study of major storms throughout the eastern United States. The ratio of major to minor axes is sometimes referred to as the shape ratio. In HMR No. 52, the storm sample was divided into regional samples in an effort to detect regional variations, but none was found. This pattern is given for a map scale

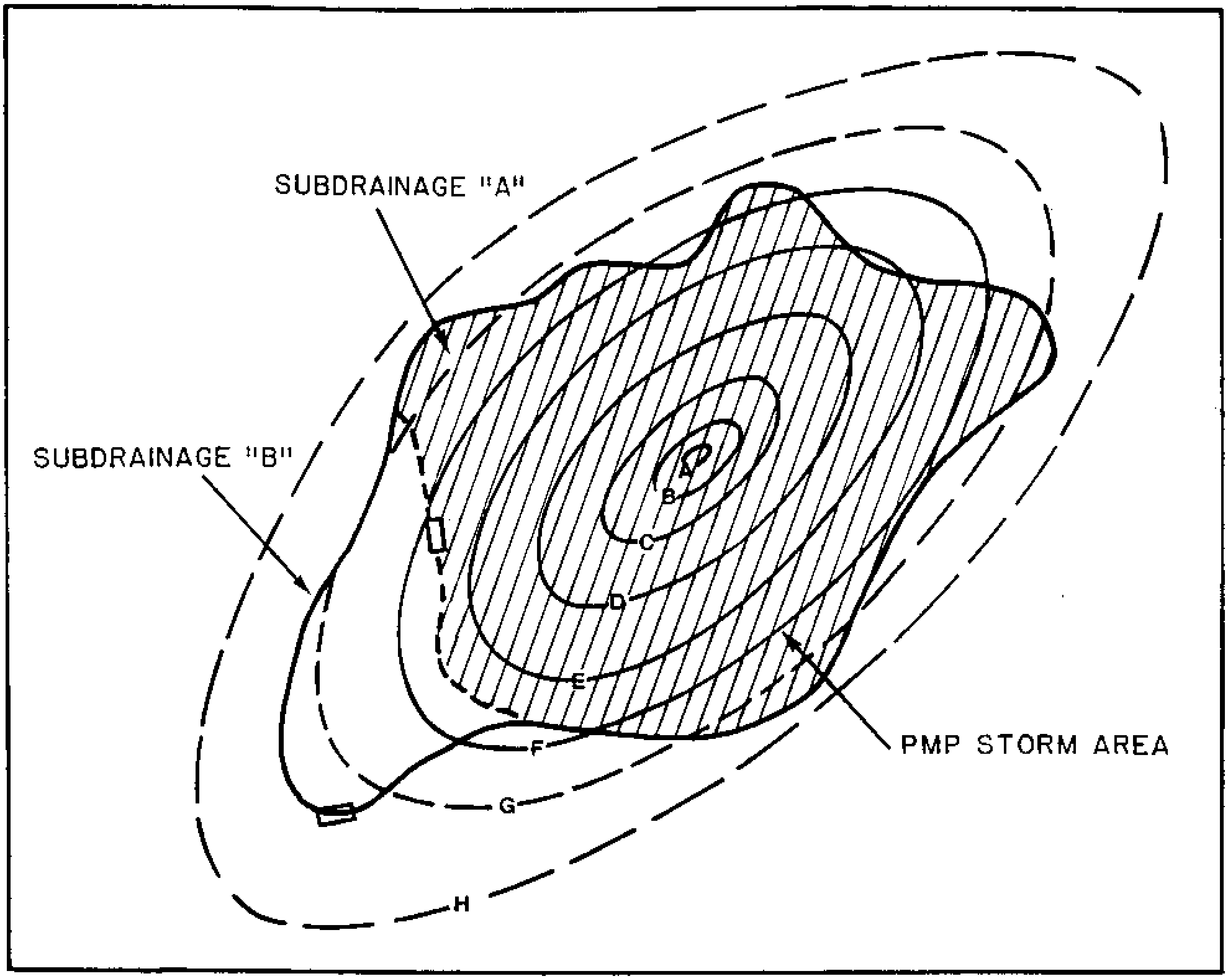


Figure 71.--Schematic diagram of idealized PMP storm pattern placed over a subdrainage ("A") illustrating the isohyets that cover a concurrent subdrainage ("B"). Solid isohyets represent PMP pattern area; dashed isohyets represent residual precipitation.

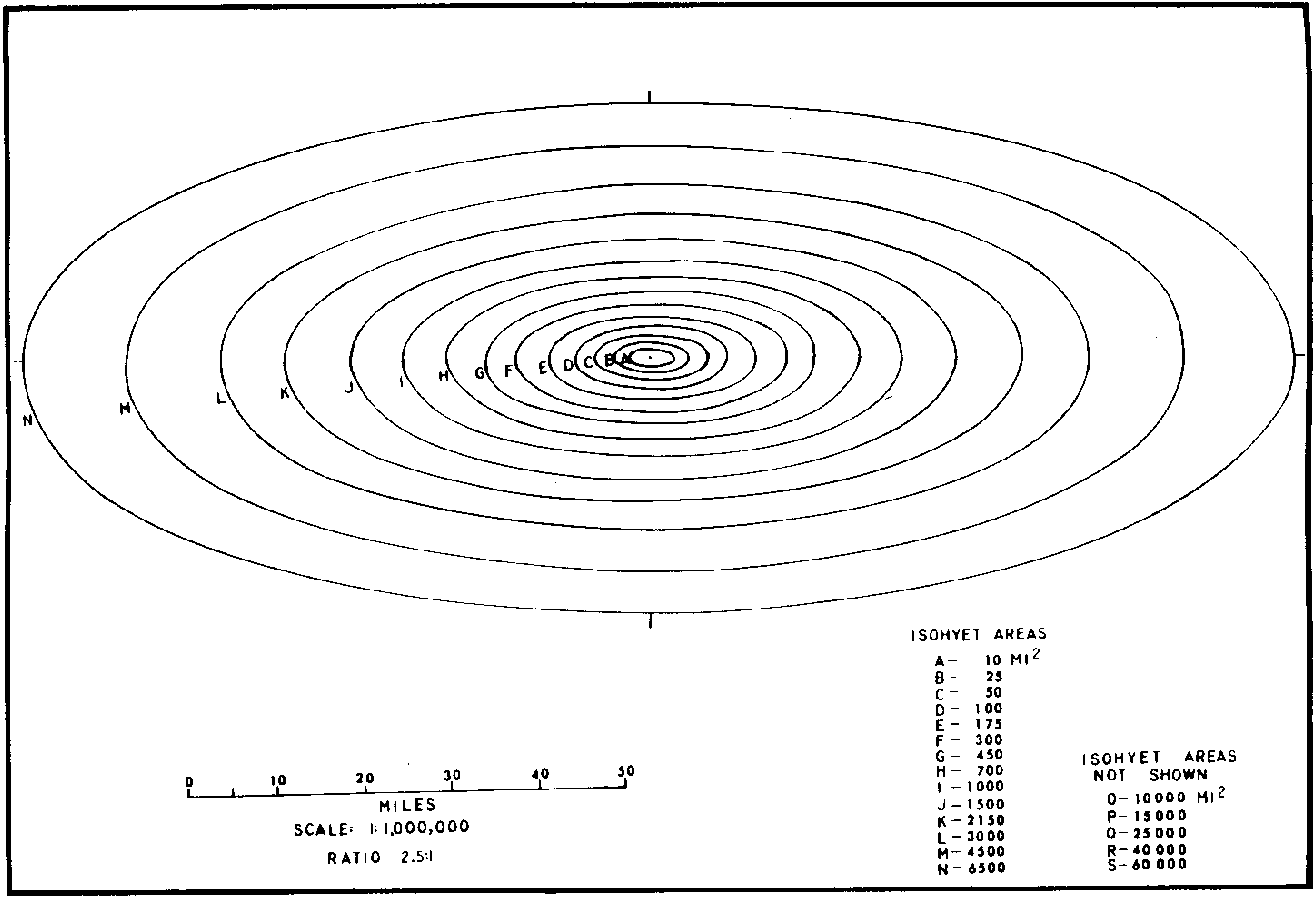


Figure 72.--Standard isohyetal pattern recommended for spatial distribution of nonorographic PMP over the Tennessee River basin (scale 1:1,000,000).

Table 11.--Axial distances (mi) for construction of an elliptical isohyetal pattern for standard isohyet areas with a 2.5 shape ratio (Complete four quadrants to obtain pattern).

Isohyet label	Standard isohyets enclosed area (mi^2)	Incremental area (mi^2)	Radial axis (deg.)* 0	15	30	45	60	90
A	10	10	2.820	2.426	1.854	1.481	1.269	1.128
B	25	15	4.460	3.836	2.933	2.342	2.007	1.784
C	50	25	6.308	5.426	4.148	3.313	2.839	2.523
D	100	50	8.920	7.672	5.866	4.685	4.014	3.568
E	175	75	11.801	10.150	7.758	6.198	5.310	4.720
F	300	125	15.451	13.289	10.160	8.115	6.953	6.180
G	450	150	18.924	16.276	12.444	9.939	8.516	7.569
H	700	250	23.602	20.301	15.521	12.397	10.622	9.441
I	1,000	300	28.209	24.263	18.550	14.816	12.965	11.284
J	1,500	500	34.549	29.717	22.720	18.146	15.549	13.820
K	2,150	650	41.363	35.577	27.200	21.725	18.614	16.545
L	3,000	850	48.860	42.026	32.130	25.662	21.989	19.544
M	4,500	1,500	59.841	51.470	39.351	31.430	26.930	23.936
N	6,500	2,000	71.920	61.860	47.294	37.774	32.366	28.768
O	10,000	3,500	89.206	76.728	58.661	46.853	40.145	35.682
P	15,000	5,000	109.225	93.973	71.846	57.383	49.168	43.702
Q	25,000	10,000	141.047	121.318	92.752	74.082	63.476	56.419
R	40,000	15,000	178.412	153.456	17.323	93.707	80.292	71.365
S	60,000	20,000	218.510	187.945	143.691	114.767	98.337	87.404

* 0° radial axis = semi-major axis
90° radial axis = semi-minor axis

To aid in construction of any additional isohyets, we provide the following relations, where a is the semi-major axis, b is the semi-minor axis, and A is area of the ellipse.

For this study, $a = 2.5b$

For a specific area, A, $b = \left(\frac{A}{2.5\pi}\right)^{1/2}$

Radial equation of ellipse $r^2 = \frac{a^2b^2}{a^2\sin^2\theta + b^2\cos^2\theta}$

where r = distance along a radial at an angle θ to the major axis of 1:1,000,000, since it was determined in recent surveys that this scale was appropriate to most user needs. The pattern in figure 72 contains isohyets labeled A (10 mi^2) to N (6,500 mi^2). These are referred to as standard isohyets and in HMR No. 52 the pattern was evaluated out to 60,000 mi^2 (additional isohyets not shown are: 10,000, 15,000, 25,000, 40,000 and 60,000 mi^2). Table 11 provides information used in constructing the isohyetal pattern in figure 72 and to develop the larger isohyets. Basic equations are included in case intermediate isohyets are required.

4.2.2 Isohyetal pattern orientation

HMR No. 52 evaluated a question that has been posed in a number of other hydrometeorological reports. The question was: Is PMP likely to occur from an optimum set of meteorological conditions? If so, does this result in a preferred orientation of the rainfall pattern? The concept says that at any particular location, there is a preferred direction or range of directions that represent the combined interaction of moisture inflow, upper level winds and other meteorological factors important in a PMP event. Major storm rainfall patterns were reviewed and figure 73 shows the general conclusions made in HMR No. 52. A range of "preferred" orientations was accepted as ±40° from those shown in figure 73. Figure 73 shows the agreement between selected major storm orientations and the analysis of preferred directions.

The concept of preferred orientations implies that if an orientation was selected that was outside the range of ± 40° from that shown on figure 73, the storm-averaged level of PMP at that location would be reduced. A model was postulated as presented in figure 74 that enables determination of the degree of reduction applicable to PMP for pattern orientations that differ between 40 and 90 degrees from the preferred orientation. In this figure, the reduction shown is dependent upon pattern area size. For pattern areas less than 300 mi^2, there is no reduction since it was formulated in HMR No. 52 that all small-area storm orientations were equally likely within current knowledge. A maximum reduction of 15 percent applies only to areas greater than 3,000 mi^2, when the orientation difference from that shown in figure 73 is more than ± 65 degrees.

4.2.3 Isohyetal Percentages

In the HMR No. 52 study a procedure was developed which permitted computations of individual isohyetal rainfall amounts for PMP storm areas of various sizes. The results are summarized in a set of tables presented in tables 12 to 15. Table 12 provides percentage values for the standard isohyetal areas for the 1st 6-hr increment (largest 6-hr amount) in a 72-hr storm. Tables 13 and 14 provide similar information for the 2nd and 3rd 6-hr increments, respectively. Table 15 gives percentages that apply to the 4th through 12th 6-hr increments. Note that in tables 12-15, storm areas intermediate to the standard areas in figure 72 have been included for convenience. In table 15, percentages are given only for isohyets of the residual precipitation, since it was accepted in HMR No. 52 that within the PMP storm, a uniform distribution (i.e., a flat value) would prevail for increments beyond the three largest 6-hr amounts.

The information in tables 12 to 15 came from nomograms developed in HMR No. 52 that uniquely provide values (in percent of the 6-hr incremental PMP amount) for any PMP storm area size up to 20,000 mi^2. These nomograms are reproduced in figures 75 to 78 in the event that they are needed for development of percentages

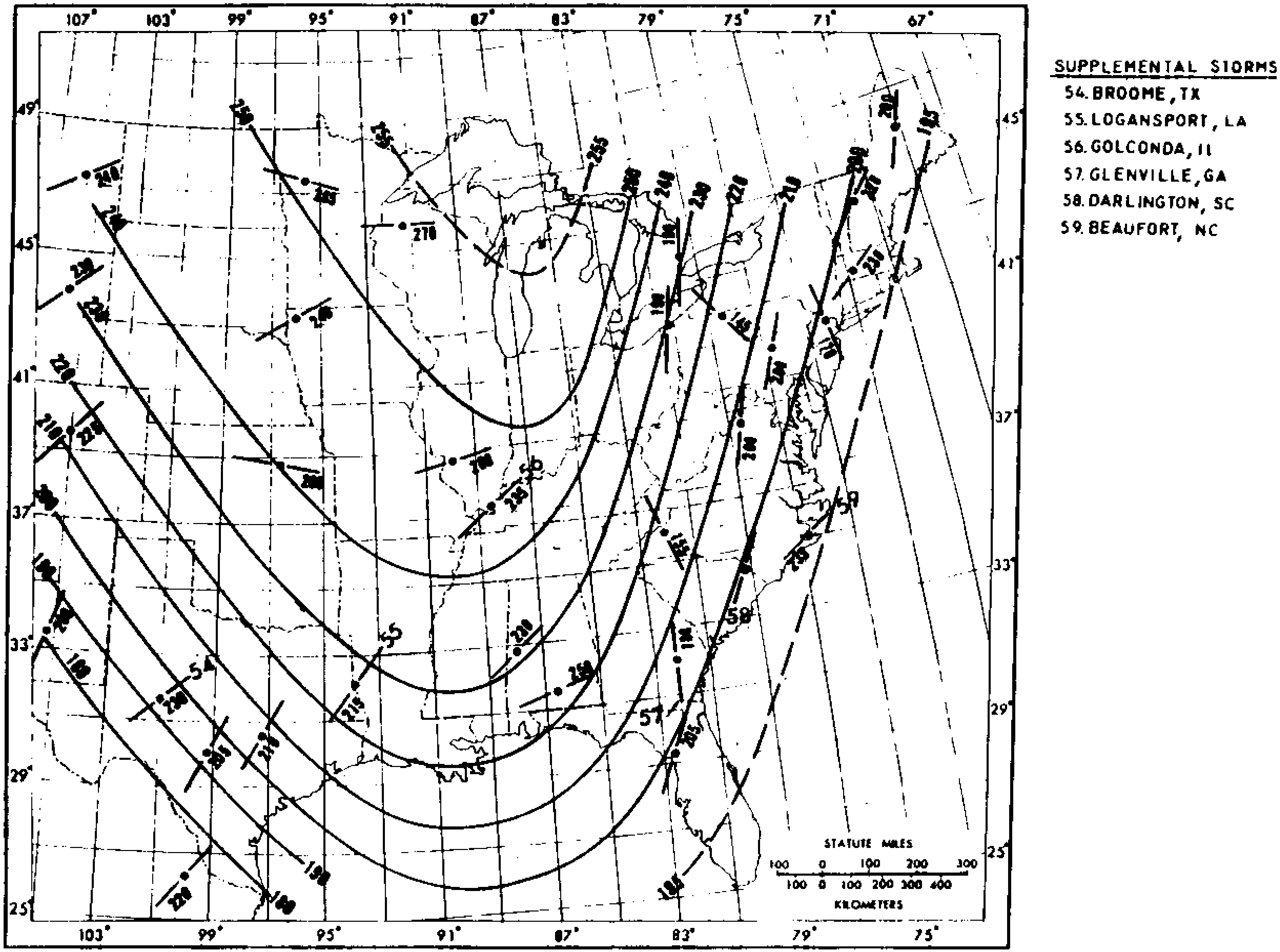


Figure 73.--Analysis of isohyetal orientations for selected major storms adopted as a recommended orientation for PMP within ±40° (Hansen et al. 1982).

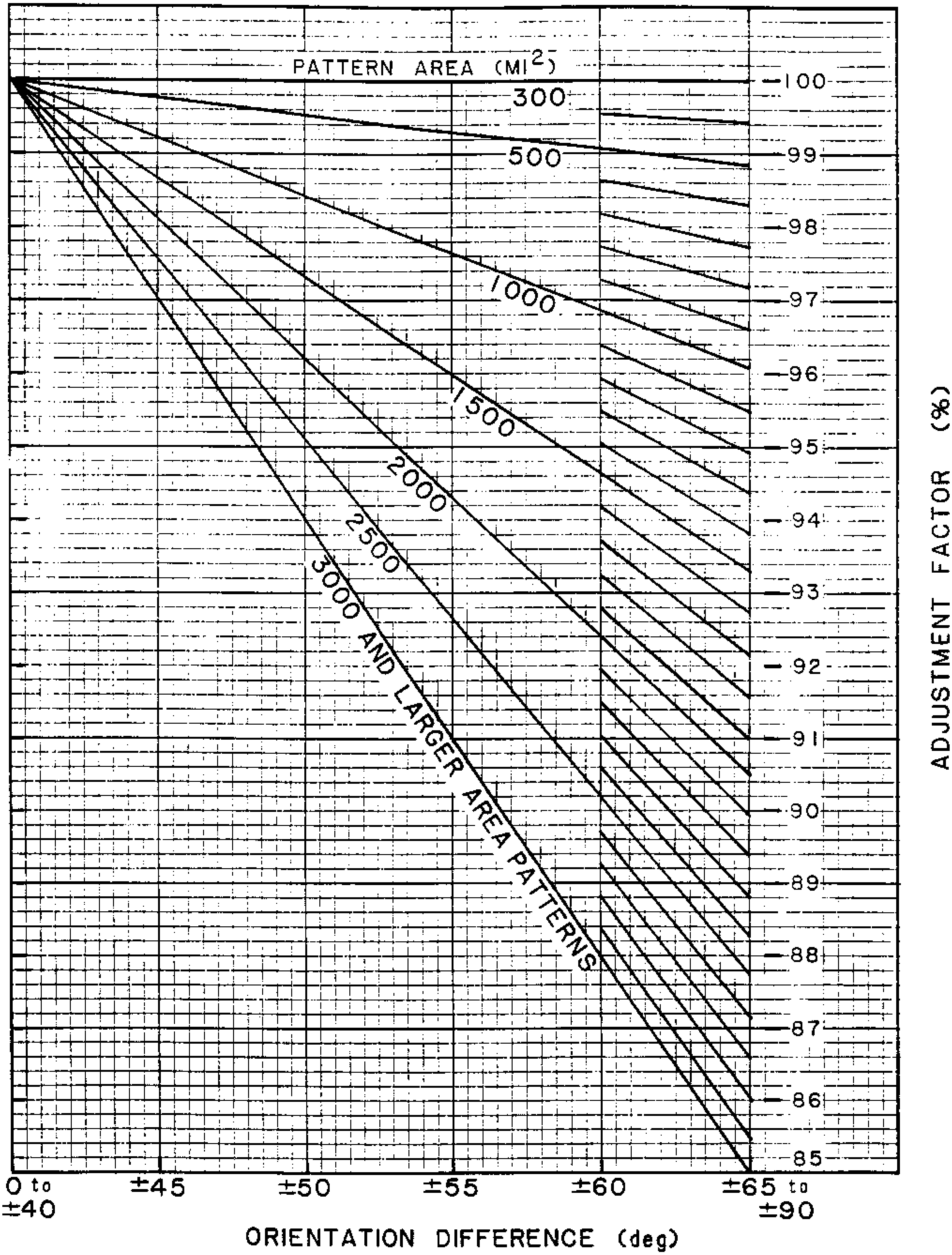


Figure 74.--Model for determining the adjustment factor to apply to isohyet values as a result of placing the pattern in figure 72 at an orientation differing from that given in figure 73 by more than 40°, for a specific location (Hansen et al. 1982).

Table 12.--1st 6-hr nomogram values at selected area sizes (Hansen et al. 1982)

Isohyet	10	17	25	35	50	75	100	140	175	220	300	360
	Storm Area (mi^2) size — Values in Percent											
A	100*	101	102	104	106	109	112	116	119	122	126	129
B	64	78	95*	97	99	102	105	108	111	114	118	121
C	48	58	67	77	92*	95	98	101	103	106	110	113
D	38	46	52	59	66	77	90*	93	96	99	103	105
E	30	37	43	48	54	62	68	78	89*	92	96	98
F	24	30	34	39	44	50	55	61	66	73	88*	90
G	19	24	28	32	35	40	44	49	53	58	65	73
H	14	19	22	25	28	32	35	39	42	46	51	56
I	10	14	17	19	22	26	28	32	34	37	42	45
J	6	9	12	14	16	19	21	24	26	28	32	35
K	2	5	7	9	11	14	16	18	20	22	25	27
L	0	1	3	5	7	9	11	13	15	17	19	21
M		0	0	1	3	5	6	8	9	10	12	13
N				0	0	0	1	2	3	4	6	7
O							0	0	0	0	1	2
P											0	0

*Indicates cusp

Table 12.--1st 6-hr nomogram values at selected area sizes (Continued)

Isohyet	450	560	700	850	1000	1200	1500	1800	2150	2600	3000	3800
	Storm Area (mi^2) size											
A	132	136	140	145	149	155	162	169	176	184	191	203
B	124	128	132	136	140	145	152	158	165	172	179	189
C	116	120	124	128	131	136	142	147	154	160	166	176
D	108	111	115	119	122	126	132	137	142	148	154	163
E	101	104	107	110	113	116	122	126	131	137	142	150
F	93	95	98	101	104	107	112	117	122	127	132	140
G	86*	89	92	94	97	100	105	108	113	118	122	130
H	63	72	84*	87	89	92	96	99	103	108	112	119
I	50	56	63	72	82*	85	88	91	95	99	102	108
J	38	43	48	54	60	68	80*	83	86	89	92	98
K	30	33	36	40	44	49	56	64	77*	80	83	89
L	23	25	27	30	32	35	41	46	52	62	74*	79
M	15	16	18	19	21	23	26	29	33	38	44	56
N	8	9	10	11	12	14	16	18	20	22	25	31
O	3	3	4	4	5	6	7	8	9	11	13	15
P	0	0	0	0	0	0	0	1	2	3	4	6
Q								0	0	0	0	0

*Indicates cusp

Table 12.--1st 6-hr nomogram values at selected area sizes (Continued)

Isohyet	Storm Area (mi ^{2}) size 4500	5500	6500	8000	10000	12000	15000	18000	20000
A	212	223	233	247	262	274	290	304	312
B	198	209	218	230	243	255	271	283	291
C	184	194	203	214	227	238	253	264	271
D	170	180	187	198	209	219	232	242	248
E	157	166	174	183	194	203	214	224	229
F	146	153	160	169	178	186	196	205	210
G	135	142	148	157	166	174	183	192	197
H	124	131	137	144	152	159	168	176	181
I	113	119	125	132	140	147	156	164	168
J	103	108	113	120	128	135	143	150	154
K	93	98	103	110	117	123	131	138	142
L	83	88	93	99	107	113	120	127	131
M	71*	76	81	87	93	99	106	113	117
N	37	48	70*	75	82	87	94	101	104
O	19	23	29	40	68*	73	80	86	89
P	8	10	13	18	26	38	65*	71	74
Q	0	0	1	3	7	11	18	28	36
R			0	0	0	0	2	6	8
S							0	0	0

*Indicates cusp

Table 13.--2nd 6-hr nomogram values at selected area sizes (Hansen et al. 1982)

Isohyet	Storm Area (mi ^{2}) size 10	17	25	35	50	75	100	140	175	220	300	360
A	100*	102	103	104	105.5	107	108	109	110	110.5	111.5	112
B	64	81.5	98*	99	100.5	102	103	104	105	106	107	108
C	48	61	72	82	96.5*	98	99	100.5	101.5	102.5	103.5	104
D	39	50	59	66.5	76	86	95*	96.5	97.5	98.5	100	101
E	30	40	48	54.5	62.5	72	79	88	95*	96	97.5	98.5
F	24	32	39	44.5	51	59.5	65	73	79	85	95*	96
G	20	27	32.5	37.5	43.5	50	55	62	66.5	72	80	85
H	14	20.5	26	30.5	36	42	47	52.5	56.5	61	67.5	72
I	10	15.5	20	24	29	34.5	38.5	43.5	47	51	57	61
J	7	12	15.5	19	23	27.5	31	35	38.5	42	47	50
K	3	7	10.5	13.5	17	21	24	27.5	30	33	37.5	40.5
L	0	1.5	5	7.5	11	14.5	17	20.5	23	26	30	33
M		0	0	1	4	7	9	12	14.5	17	20.5	23
N				0	0	0	1	3.5	5	7.5	10	12
O							0	0	0	0	1	3
P											0	0

*Indicates cusp

Table 13.--2nd 6-hr nomogram values at selected area sizes (Continued)

Isohyet	Storm Area (mi ^{2}) size 450	560	700	850	1000	1200	1500	1800	2150	2600	3000	3800
A	113	114	114.5	115	116	116.5	117	118	118.5	119	119.5	120.5
B	109	109.5	110	111	112	112.5	113	114	114.5	115.5	116	117
C	105	106	107	107.5	108.5	109	110	110.5	111	112	112.5	113.5
D	102	102.5	104	104.5	105	106	107	108	108.5	109.5	110	111
E	99.5	100.5	101	102	103	104	105	105.5	106.5	107	108	109
F	97	98	99	100	101	102	103	104	104.5	105.5	106	107
G	95*	96	97	98	99	99.5	100.5	101.5	102	103	104	105
H	77.5	85	95*	96	97	97.5	99	99.5	100	101	102	103
I	66	71.5	78	85	95*	96	97	98	99	99.5	100.5	101.5
J	54.5	60	65.5	71	76	82.5	95.5*	96	97	98	99	100
K	44.5	49	54	58.5	63	68	75.5	83	96*	96.5	97	98
L	36.5	40	44	48	51	55	60.5	66	73	83	96*	97
M	25.5	28.5	32	35	38	41	45	49.5	54	60.5	67	81
N	14	17	19.5	22	24	27	31	34	37.5	41.5	45	52.5
O	4.5	6.5	9	11	12.5	14.5	17	19.5	22	25.5	28.5	34
P	0	0	0	0	0	0	0	1.5	4	7	9	13.5
Q								0	0	0	0	0

*Indicates cusp

Table 13.--2nd 6-hr nomogram values at selected area sizes (Continued)

Isohyet	Storm Area (mi ^{2}) size 4500	5500	6500	8000	10000	12000	15000	18000	20000
A	121	122	122	123	124	124.5	125	126	126
B	117	118	119	120	120.5	121	122	122.5	123
C	114	115	115.5	116.5	117	118	119	119.5	120
D	112	112.5	113	114	115	116	117	118	118
E	109.5	110.5	111	112	113	114	115	116	116
F	108	108.5	109	110	111	112	113	113.5	114
G	105.5	106.5	107	108	109	110	111	112	112
H	103.5	104.5	105	106	107	108	109	110	110
I	102	103	104	104.5	105.5	106.5	107	108	108.5
J	100.5	101.5	102	103	104	105	106	106.5	107
K	99	100	100.5	101.5	102.5	103	104	105	105
L	97.5	98.5	99	100	101	102	102.5	103.5	104
M	96*	97	97.5	98.5	99	100	101	102	102
N	59	72.5	95.5*	96	97	98	99	99.5	100
O	39	46	52.5	66	95*	96	97	97.5	98
P	17	22	27.5	37	50	64	96*	96.5	97
Q	0	0	1	6	14	21	34	47	55
R		0		0	0	0	0	4.5	7
S									0

*Indicates cusp

Table 14.—3rd 6-hr nomogram values at selected area sizes (Hansen et al. 1982)

Isohyet	Storm Area (mi ^{2}) size											
	10	17	25	35	50	75	100	140	175	220	300	360
A	100*	100.6	101	101.3	101.6	102	102.3	102.6	102.8	103.1	103.4	103.6
B	65	83.5	99*	99.4	99.8	100.3	100.7	101	101.3	101.5	101.9	102.1
C	48	63	74.5	85.5	98.5*	99	99.3	99.7	100	100.3	100.7	100.9
D	39	51	60.5	69	78.5	90	98.6*	99	99.2	99.5	99.8	100.1
E	30	40	48.5	55.5	63	73.5	81.5	92	98.8*	99	99.3	99.5
F	24	33	40	46.5	53.5	61.5	68	76.5	83	89	99.0*	99.2
G	20	28	34	39.5	46	53	59	66	71	77	86	92
H	14	21	27	32.5	37.5	44	49	55	59.5	64	72	76.5
I	10	16.5	21.5	26.5	31.5	37.5	42	47.5	51	55.5	62	66
J	6.5	12.5	17	21	26	31.5	35.5	40.5	44	47.5	53	56
K	3	7.5	11.5	15	19.5	24.5	28	32.5	35	38.5	43	46
L	0	1.5	5	8.5	12	16.5	20	24	26.5	29.5	33.5	36
M		0	0	1	4	8.5	11.5	15	18	20.5	24.5	27
N				0	0	0	1	4.5	7	10	14	16
O							0	0	0	0	2	4
P											0	0

*Indicates cusp

Table 14.—3rd 6-hr nomogram values at selected area sizes (Continued)

Isohyet	Storm Area (mi ^{2}) size											
	450	560	700	850	1000	1200	1500	1800	2150	2600	3000	3800
A	103.8	104	104.2	104.4	104.6	104.7	105	105.2	105.3	105.5	105.7	105.8
B	102.4	102.7	102.9	103.2	103.3	103.5	103.8	104	104.2	104.4	104.6	104.8
C	101.2	101.5	101.7	102	102.3	102.5	102.7	102.9	103.2	103.4	103.5	103.8
D	100.3	100.6	100.8	101.1	101.3	101.5	101.7	102	102	102.4	102.5	102.8
E	99.8	100	100.2	100.4	100.6	100.8	101	101.2	101.3	101.5	101.7	101.9
F	99.5	99.7	99.9	100.1	100.3	100.4	100.7	100.8	101	101.2	101.3	101.5
G	99.2*	99.4	99.6	99.7	99.9	100	100.3	100.4	100.6	100.7	100.9	101.1
H	84	91	99.2*	99.4	99.6	99.7	100	100.1	100.3	100.4	100.5	100.7
I	71	77.5	85	92	99.3*	99.5	99.7	99.8	100	100.1	100.2	100.5
J	60	64.5	70.5	76.5	82.5	89.5	99.4*	99.5	99.7	99.8	99.9	100.1
K	50	54	58.5	62.5	67	72.5	81	89	99.5*	99.5	99.6	99.8
L	39.5	43	47	50.5	54	58.5	65.5	72.5	80.5	90.5	99.3*	99.5
M	30	33	37	40	43	46.5	51.5	56.5	61	69	76	88.5
N	19	22.5	25.5	28.5	31	34	38	42	46.5	52	57	67
O	7	10	13	15.5	17.5	20.5	24	27	30.5	34	37.5	43.5
P	0	0	0	0	0	0	0	2.5	5.5	9	12	16.5
Q									0	0	0	0

*Indicates cusp

Table 14.—3rd 6-hr nomogram values at selected area sizes (Continued)

Isohyet	Storm Area (mi^2) size 4500	5500	6500	8000	10000	12000	15000	18000	20000
A	106	106.2	106.4	106.6	106.8	107	107.2	107.4	107.5
B	105	105.3	105.5	105.7	106	106.2	106.5	106.7	106.8
C	104	104.3	104.5	104.8	105	105.3	105.5	105.8	105.9
D	103.1	103.2	103.5	103.7	104	104.2	104.4	104.6	104.7
E	102.1	102.3	102.5	102.7	101.9	102.1	102.3	102.4	102.5
F	101.7	101.8	102	102.2	102.4	102.6	102.8	103	103
G	101.2	101.4	101.5	101.7	101.9	102.1	102.3	102.4	102.5
H	100.9	101.1	101.2	101.4	101.6	101.8	102	102.2	102.2
I	100.6	100.8	100.9	101.1	101.3	101.5	101.7	101.8	101.9
J	100.2	100.4	100.5	100.7	100.9	101	101.2	101.3	101.4
K	99.9	100	100.2	100.3	100.5	100.7	100.8	101	100.7
L	99.6	99.7	99.8	100	100.2	100.3	100.5	100.6	100.7
M	99.3*	99.4	99.5	99.6	99.8	99.9	100.1	100.2	100.2
N	76	88	98.9*	99	99.2	99.3	99.5	99.6	99.7
O	49	57	65	79	98.7*	98.8	99	99.1	99.2
P	21	27.5	34.5	44.5	59	71.5	98*	98.7	98.2
Q	0	0	1	8	18	27.5	42	54.5	66
R			0	0	0	0	1	7.5	12
S							0	0	0

*Indicates cusp

Table 15.—4th to 12th 6-hr nomogram values at selected area sizes (Hansen et al. 1982)

Isohyet	Storm Area (mi^2) size 10	17	25	35	50	75	100	140	175	220	300	360
A	100											
B	65	83.5	100									
C	48	62.5	74.5	86	100							
D	39	50.5	60.5	68.5	78.5	89.5	100					
E	30	40	48.5	55	63	73	81.5	91	100			
F	24	33	40	46	53.5	61.5	68	76.5	83	89	100	
G	20	27.5	34	39	46	53	59	65.5	71	77	86	91.5
H	14	21	27	31.5	37.5	44	49	55	58.5	64	72	77
I	10	16	21.5	26	31.5	37	42	47.5	51	55	62	65
J	6.5	12	17	21	26	31	35.5	40	44	47	53	55.5
K	3	7.5	11.5	15	19.5	24	28	32	35	38.5	43	46
L	0	0.5	5	8.5	12	16	20	23.5	26.5	29	33.5	36
M		0	0	0.5	4	8.5	11.5	15	18	20.5	24.5	27
N				0	0	0	1	4	7	9.5	14	16
O							0	0	0	0	2	4
P											0	0

Table 15.--4th to 12th 6-hr nomogram values at selected area sizes (Continued)

Isohyet	Storm Area (mi^2) size 450	560	700	850	1000	1200	1500	1800	2150	2600	3000	3800
A												
B												
C												
D												
E												
F												
G	100											
H	84	91	100									
I	71	77.5	85	92	100							
J	60	64.5	70.5	77	82.5	89.5	100					
K	50	53.5	58.5	62	67	72	81	89	100			
L	39.5	43	47	50.5	54	58.5	65.5	72.5	80.5	90	100	
M	30	33	37	40	43	46.5	51.5	56	61	69	76	88.5
N	19	22	25.5	28	31	33.5	38	41.5	46.5	51.5	57	67
O	7	9.5	13	15	17.5	20	24	26.5	30.5	33.5	37.5	43.5
P	0	0	0	0	0	0	0	2.5	5.5	9	12	17
Q							0	0	0	0	0	

Table 15.--4th to 12th 6-hr nomogram values at selected area sizes (Continued)

Isohyet	Storm Area (mi^2) size 4500	5500	6500	8000	10000	12000	15000	18000	20000
A									
B									
C									
D									
E									
F									
G									
H									
I									
J									
K									
L									
M	100								
N	76	88	100						
O	49	56.5	65	79	100				
P	21	27	34.5	44	59	71	100		
Q	0	0	1	8	18	27	42	54	66
R			0	0	0	0	1	7	12
S							0	0	0

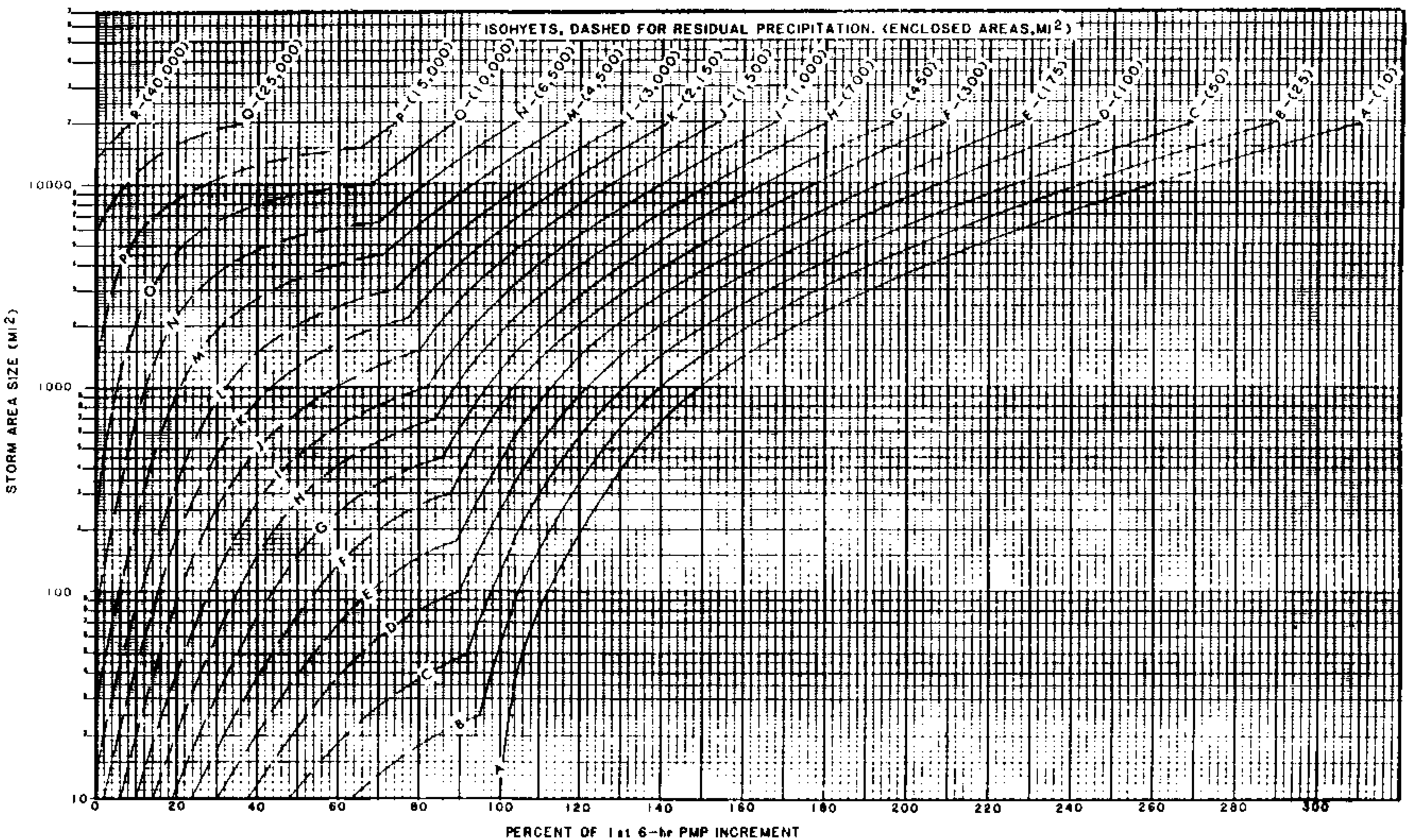


Figure 75.--Nomogram for the 1st 6-hr PMP increment and for standard isohyet area sizes between 10 and 40,000 mi^2 (Hansen et al. 1982).

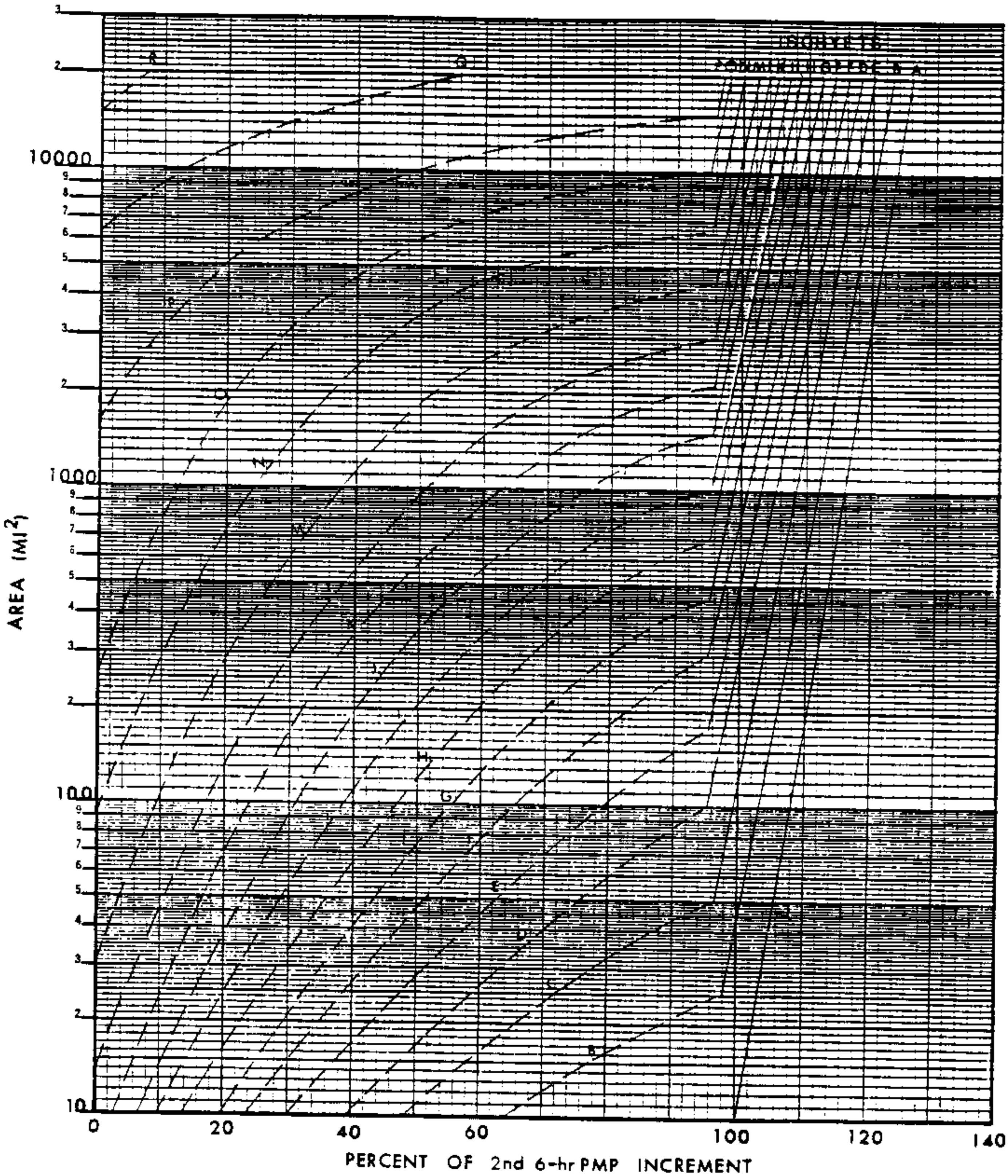


Figure 76.--Nomogram for the 2nd 6-hr PMP increment and for standard isohyet area sizes between 10 and 40,000 mi^2 (Hansen et al. 1982).

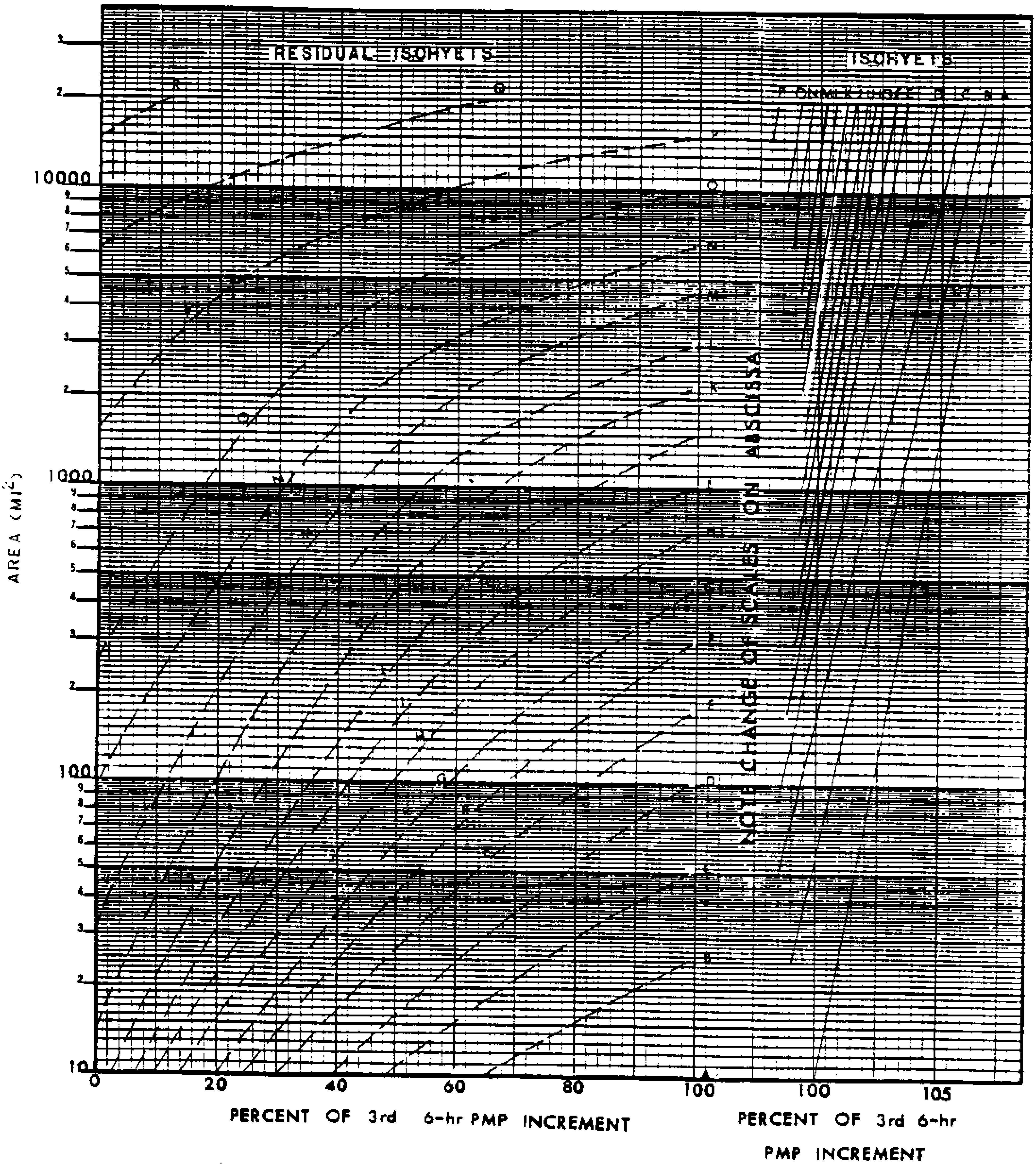


Figure 77.--Nomogram for the 3rd 6-hr PMP increment and for standard isohyet area sizes between 10 and 40,000 mi^2 (Hansen et al. 1982).

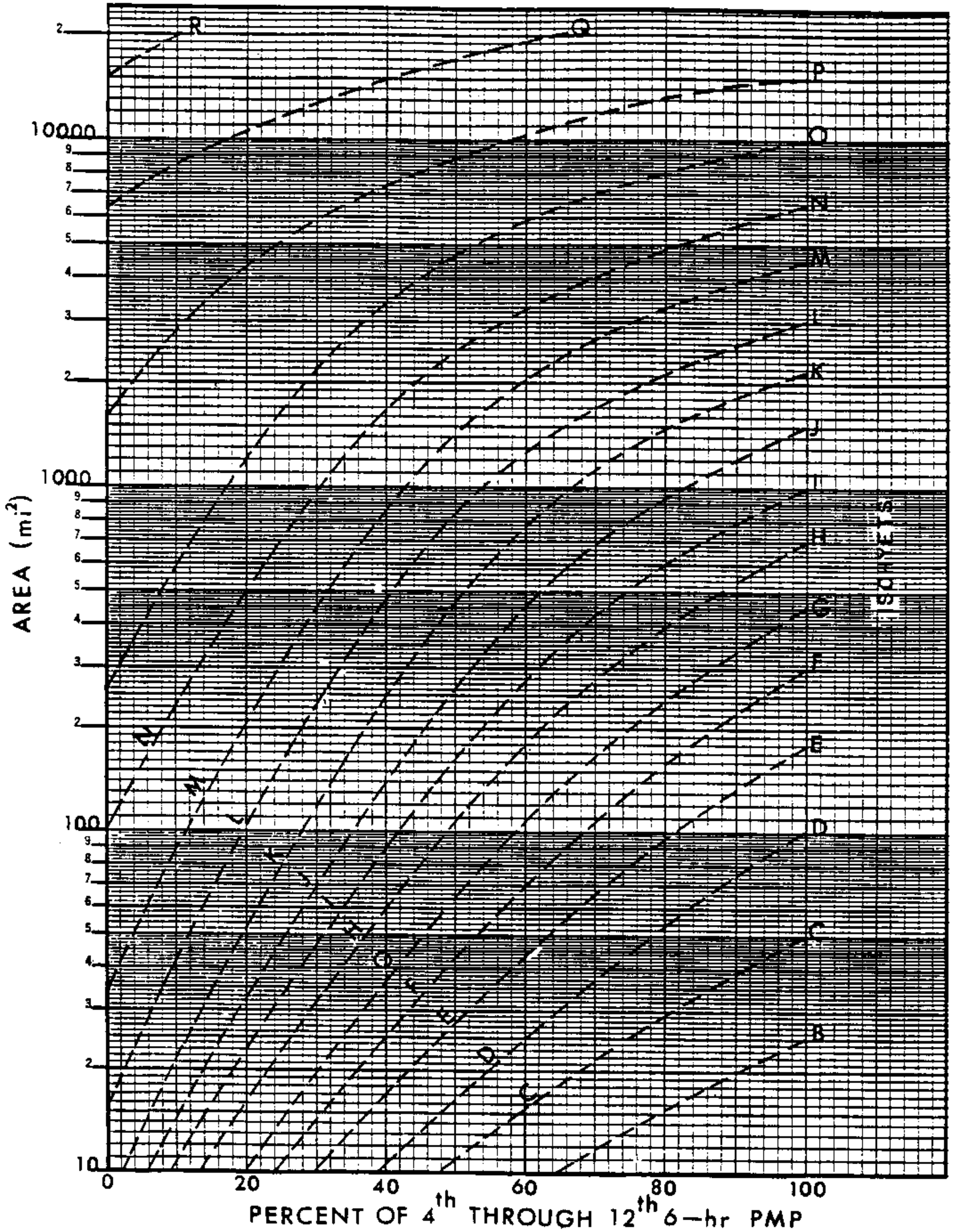


Figure 78.--Nomogram for the 4th through 12th 6-hr PMP increment and for standard isohyet area sizes between 10 and 40,000 mi^2 (Hansen et al. 1982).

for intermediate isohyets. In these figures, amounts for PMP isohyets are shown as solid curves, and for residual isohyets as dashed curves. To use this information, enter the ordinate axis at the PMP storm area and read across to the respective isohyetal curve intersection according to the scale of the abscissa. Curves for intermediate isohyets can be determined by linear interpolation between the curves shown. Note the scale change between the right and left portions of figure 77 for the 3rd 6-hr increment. The abscissa gives amounts as percent of the respective 6-hr increment. Therefore, it is necessary to multiply these percents times the 6-hr incremental amount to obtain an isohyet value in inches.

4.3 Concepts for Application

4.3.1 In the Western Tennessee Valley

In the nonorographic western portion of the Tennessee Valley, the areal distribution is the same as provided in HMR No. 52. In the case of areal distribution of TVA precipitation, first determine the incremental isohyetal percentages for PMP. Then apply the respective conversion factor (0.58, 0.55, or 0.53) according to whether the primary basin is mostly rough, intermediate or smooth. The procedure involves placement of the standard isohyet pattern over the drainage such that as many complete isohyets are contained as possible. In general, the result is that the axes of the drainage and the elliptical pattern are roughly similar. The intent is to fit the pattern to obtain the maximum volume of precipitation in the drainage.

The areal distribution procedure in HMR No. 52 is based on a set of smooth DAD relations. In the present study, DAD relations are a function of the respective procedure. The small-basin procedure provides storm-centered DAD relations up to 100 mi^2 and the large-basin procedure provides storm-centered DAD relations for areas greater than 100 mi^2. To join the two sets of DAD relations for any specific application requires some smoothing. For application to basins greater than 500 mi^2, the DAD relations in figure 52 are adequate. However, if the areal distribution is needed for a basin less than 500 mi^2, it will be necessary to first develop the DAD relations for both small and large basin procedures, and then smooth to create a consistent single set of DAD curves.

For the areal distribution, the trial process outlined in HMR No. 52 is recommended to determine the area size of the PMP storm. This process requires the selection of a number of standard pattern areas both larger and smaller than the drainage area for which respective volumes of precipitation into the specific drainage area are determined. The storm area that yields the maximum volume is then selected by definition as the area of the PMP storm for that basin.

After the PMP storm area has been determined, tables 12-15 or nomograms (fig. 75-78) are used to obtain isohyet percentages. When the percentages are known, then the average depth of PMP (and residual precipitation) that occurs in the drainage can be determined for each 6-hr increment (customarily by planimetering). This is the basin-averaged PMP (or TVA precipitation).

4.3.2 In the Eastern Tennessee Valley

The eastern portion of the Tennessee Valley contains the slopes of the Appalachian Mountains. The terrain in this region affects the areal distribution of storms and thus, the procedure proposed for areal distribution in section 4.3.1. The effect of terrain is to warp the isohyetal pattern obtained as described in section 4.3.1. Thus, it was necessary to modify the isohyetal pattern (fig. 72) obtained from HMR No. 52 to account for terrain effects.

Two concepts have been added in the present study that affect the warping of the elliptical pattern. The first is that the greatest orographic influence is likely to occur on the principal slopes of the drainage, which for most drainages lie towards the perimeter of the drainage. Essentially, this means that for those basins represented as a valley surrounded by major slopes, the total-storm isohyetal pattern will likely be displaced away from the basin-centered position postulated for nonorographic PMP. It is recognized, however, that many basins do not conform to such simplistic description, and more complex results are likely. The following rules have been established to govern adjustments to the elliptical pattern in the eastern Tennessee Valley.

1. Locate the specific drainage on the 2-yr 24-hr analysis (fig. 59), and note the position of the highest 2-yr 24-hr precipitation amount within the basin.

2. Displace the center of the elliptical pattern (fig. 72) in the direction of the maximum 2-yr 24-hr precipitation from step 1, but not closer to the basin border than 10 mi.

These rules derive from considering the effects of inflow winds on the relative slopes in the Tennessee Valley, and assume that the maxima shown on the 2-yr 24-hr analysis reflect conditions for storm centering that are likely to occur in the PMP storm. Under this guidance, it is conceived that a situation may exist such that in a highly orographic basin, no displacement is necessary. However, for most basins >500 mi^2, it is expected that some displacement will result. For most smaller basins or for long narrow basins, the limitation of 10 mi from the basin border will not allow displacement.

In determining whether a pattern is to be displaced, observe the following guidance:

a. if the basin-centered pattern is already less than 10 mi from the basin border, do not displace the pattern.

b. all displacements are to be allowed only in the direction of the maximum 2-yr 24-hr amount. If the maximum is represented by a length of isohyet rather than a point, the allowable directions are those that range from one end of the maximum isohyet to the other.

c. do not change the orientation of the pattern during displacement.

d. do not redetermine the size of PMP storm according to HMR-52 procedures for the displaced pattern.

The second concept is that the analysis of 2-yr 24-hr precipitation-frequency values (fig. 59) represents an acceptable indicator of the terrain effects on the distribution of PMP in the eastern Tennessee Valley. The 100- and 2-yr precipitation-frequency analysis, as well as mean annual or seasonal precipitation maps, have been used in other studies for developing isohyetal patterns in orographic regions. In this study, a precipitation-frequency map was selected as being most representative of storm conditions. Mean annual or seasonal maps were not used since they were considered to unduly increase rainfall magnitudes on slopes for a storm situation. A portion of the increase on exposed slopes on mean annual or seasonal maps is attributable to the more frequent occurrence of light rains over higher elevations than over surrounding valleys.

Comparison of the isopluvial pattern on the 2- and 100-yr maps showed similar patterns. Though there is a tendency, in general, for the maxima in the isopluvial pattern to be at lower elevations for the longer return periods, this was not supported from the analysis prepared for this study. Therefore, the 2-yr map was selected for use here, because greater confidence can be placed in the results of the frequency analysis for the station record lengths available for this study.

The warping procedure is a function of basin area size and location. In the eastern region (both mountainous and non-mountainous areas) for basins ≤ 100 mi^2, the nonorographic elliptical pattern adjusted, as discussed in section 4.3.1, is used as the basis for the warping procedure. The 2-yr 24-hr isopluvial pattern covering the basin is converted to a percentage of the 2-yr 24-hr amount at the center of the isohyetal pattern. Then, the 2-yr 24-hr percental analysis and the elliptical pattern are graphically multiplied and the results analyzed to provide the warped isohyets.

For basins >100 mi^2 in the nonmountainous east, the nonorographic elliptical PMP isohyets adjusted for the TSF (sect. 3.5.2) and displaced according to the rules above are multiplied by the 2-yr 24-hr percental analysis (based on the center of the displaced pattern). In the mountainous east, the displaced elliptical PMP isohyets adjusted for the TAF (sect. 3.5.3) are multiplied by the 2-yr 24-hr percental analysis (based on the center of the displaced pattern).

Because all of these modifications may result in somewhat different basin average depths than was determined before areal distribution, it is important to adjust the final warped isohyets by ratioing to reestablish the original average depths. Refer to the procedures and examples in chapter 5 for clarification of these concepts.

Note: For those portions of the western region in figure 1 that are designated as rough in figure 67, no modification of the areal distribution is applied in this study, because the 2-yr 24-hr analysis for this region does not support any orographic modification.

5. PROCEDURES FOR COMPUTING PMP AND TVA PRECIPITATION AND DETERMINING AREAL DISTRIBUTION, INCLUDING EXAMPLES

5.1 Introduction

The basic concepts for deriving PMP and TVA precipitation are described in chapter 2 for basins less than 100 mi^2 and in chapter 3 for basins between 100 and 3,000 mi^2. The principles of areal distribution are presented in chapter 4 for all areas above 10 mi^2. This chapter deals with procedures needed to obtain answers for any number of possible options that might be considered. There are at least five types of options available in this study, as follows:

1. location (western vs. nonmountainous east vs. mountainous east) (refer to fig. 1)
2. area size (small basin vs. large basin)
3. precipitation (PMP vs. TVA)
4. basin average values vs. areally distributed values
5. values for primary basin vs. values for concurrent basins

The possible combinations of options are more than can reasonably be considered in terms of individual description of necessary steps. Therefore, we have elected to provide some key procedures and examples that will provide sufficient guidance on how to obtain answers for those options not explicitly described so that the user may develop his/her own stepwise procedure.

In this chapter, the individual procedures are presented as a series of steps designed to obtain a result. Note that references to "step" in any procedure always means within that particular procedure unless noted otherwise by a reference to another section.

5.2 Small Basin ($\leq$100-mi^2) Procedures (All Regions)

In chapter 2, consideration for terrain has been included in the analysis presented in figures 22 and 23 for 6-hr 1-mi^2 PMP and figures 24 and 25 for 6-hr 1-mi^2 TVA precipitation. Therefore, it is not necessary to differentiate the portion of the Tennessee Valley region that is orographic, when determining PMP or TVA precipitation. However, the effects of terrain on the elliptical pattern need to be considered in the non-mountainous and mountainous eastern regions.

5.2.1 Computation of PMP Estimate

The following steps outline the procedure for determining non-areally distributed PMP for basins within the Tennessee Valley that are smaller than 100 mi^2. If a decision is made not to consider areal distribution there can be no basin-averaged PMP nor evaluation of concurrent precipitation.

Step

1. Outline the basin of interest on figure 22 or 23, and determine an average value of the 6-hr 1-mi^2 PMP for the basin.

2. Obtain depth-durational values from 1 to 24 hr for the average value in step 1 from figure 41. These are storm-centered relations.

3. Use the depth-areal relations in figure 26 to reduce the depth-duration values in step 2 to the area size of the drainage. This figure provides storm-centered relations.

4. Plot the areally reduced values in step 3 and fit with a smooth curve. Obtain amounts for all required durations from the smooth curve. The results yield storm-centered average depth values of total-storm PMP for the basin of interest.

5. Obtain incremental amounts through successive subtraction of each durational value in step 4 from the next longer durational value.

6. Select a time distribution that is in accord with the instructions given in section 2.2.14 and arrange the incremental PMP from step 5 in that sequence.

5.2.2. Computation of TVA Precipitation

Step

1. Obtain the 6-hr 1-mi^2 TVA precipitation by placing an outline of the drainage over figures 24 or 25 and determine the average value for the basin.

2. Determine the length of the storm of interest. The factors that follow for selected durations (based on figs. 37-40) are obtained from table 7. Multiply the appropriate factor times the 6-hr 1-mi^2 TVA average depth from step 1 to adjust to the other durations of the storm:

Storm Duration (hr)	3	6	12	24
Factor	0.80	1.00	1.13	1.24

3. Refer to figures 37 to 40 to obtain respective hourly adjusted amounts based on the adjusted value from step 2. Enter these figures with the product from step 2 on the ordinate scale. If durations other than shown in figures 37 to 40 are required, smooth curves may be constructed as necessary to determine interpolated amounts.

4. Obtain the areal reduction factors from figure 26 for the duration of the storm. Multiply the depths from step 3 by the areal reduction factors. (Subtract consecutive durational amounts to obtain incremental values.)

5. Values from step 4 are plotted on a depth-duration diagram and a smooth curve fitted. The results are storm-centered average depths of TVA precipitation.

6. Choose a time sequence from the instructions in section 2.2.14 for hourly and 6-hr increments. The most critical sequence of the several sequences permitted is determined primarily on the basis of the derived hydrograph.

5.3 Procedure for Basins Between 100 and 3,000 mi^2

In the following sections, procedures are presented for computing PMP and TVA precipitation for large basins (100 to 3,000 mi^2). These procedures are adopted from the discussions in sections 3.3. and 3.4. Because of the different procedures proposed for individual basins dependent upon location in the Tennessee Valley, continued reference should be made to figures 67 and 68. These figures show the separation between eastern and western regions, as well as the distribution of rough, intermediate and smooth terrain types.

The computational processes have been broken down into units that cover PMP, TVA precipitation, areal distribution, terrain adjustments, and concurrent drainages. Where the processes differ regionally, the units have been separated to explain the respective differences.

5.3.1 Computation of PMP Estimate

In contrast to the small basin procedure, no map analysis of PMP has been made from which to obtain storm-area averaged PMP values. Instead, the following alternative method is used.

Step

1. Scale 6-, 12-, 18-, 24-, 48- and 72-hr precipitation depths for a few area sizes larger and smaller than the basin area from figure 52. These are nonorographic storm-averaged PMP values applicable to Knoxville Airport, TN.

2. From figure 54 or 55, read a regional adjustment percentage for the centroid of the drainage being considered.

3. Multiply the DAD values in step 1 by the adjustment in step 2 to create a set of DAD curves applicable to the location of the drainage. If areal distribution is not considered, the storm-averaged nonorographic PMP estimates are read off these DAD curves for the area size of the drainage. If basin-averaged values are desired, areal distribution is important; then, using the results of the procedure outlined in section 5.4, adjust the storm-averaged PMP for pattern orientation and basin shape to obtain basin-averaged PMP. The following steps are followed only if areal distribution is not required, but they will not provide basin-averaged results.

4. Plot the values in step 3 for the area size of the drainage as depth vs. duration and draw a smooth curve to enable interpolation of 6-hr amounts.

5. To obtain a 6-hr incremental PMP value, subtract each durational value from the next longer 6-hr durational value.

6. Determine the applicable TSF from section 5.4.3.1 for basins in the west or nonmountainous east, or the TAF from section 5.4.3.2 for basins in the mountainous east, or by the results of section 5.4.3.3 for basins in more than one region.

7. Multiply the appropriate terrain factor from step 6 times the incremental values from step 5.

8. Incrementally add the values in step 7 to get a depth-duration curve of total PMP. Unless areal distribution was considered in step 3, this total PMP estimated is not a basin-average value, but rather a storm-averaged value modified for terrain effects.

5.3.2 Computation of TVA Precipitation

Note: TVA precipitation values can be obtained following the procedure in Section 5.3.1, substituting figure 53 for figure 52 in Step 1, or if PMP has already been determined for the drainage, follow the steps below.

Step

1. Choose a TVA storm length from among 3, 6, 12, 24 or 72 hr.

2. For the duration chosen in step 1, read the corresponding value of total PMP from section 5.3.1, step 8 (see Note above).

3. From figure 67 or 68, determine whether the majority of the drainage is covered by rough, intermediate, or smooth terrain.

4. If step 3 is rough, multiply step 2 by 0.58; if step 3 is intermediate, multiply step 2 by 0.55, and if step 3 is smooth, multiply step 2 by 0.53, (see discussion, sect. 2.2.7.1).

5. For the storm length chosen in step 1 and the adjusted PMP from step 4, determine the durational values of TVA precipitation from the appropriate figure (37 to 40) for TVA storm lengths of 3 to 24 hr and from figure 79 for a TVA storm length of 72 hr. The results are storm-centered (unless areal distribution is applied) average TVA precipitation.

5.4. Computation of Areal Distribution of PMP and TVA Precipitation (Includes Modification for Terrain Effects)

The basic procedure for computing the areal distribution of PMP in this study is applicable to all basin areas (>10 mi^2), regardless of whether PMP has been derived from the small- or the large-basin procedures. Instances where the small- or large-basin procedures differ regarding input values needed for the areal distribution will be noted. The recommended procedure for areal distribution has been taken from HMR No. 52 (Hansen et al. 1982). For basins

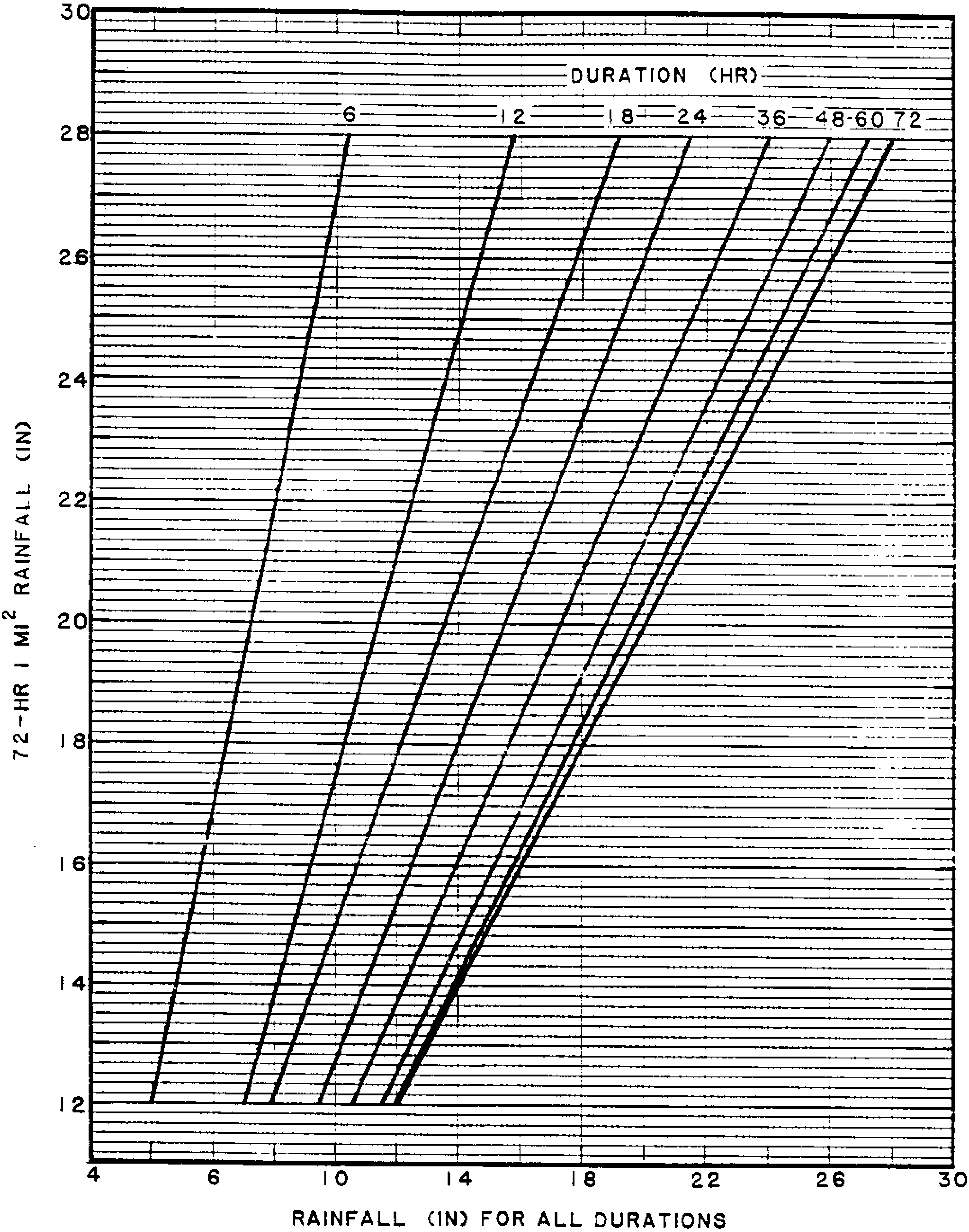


Figure 79.--Depth-duration relations for 72-hr TVA precipitation storm.

whose area size is less than 500 mi^2, it is necessary first to develop a set of depth-area-duration relations from both the small- and large-basin procedures. The following steps describe this procedure (TVA precipitation figures are given in parentheses). Areal distribution is the procedure that allows basin-averaged PMP and TVA precipitation to be determined from storm-averaged DAD relations.

Step (Small-basin DAD)

1. Determine the 6-hr 1-mi^2 PMP (TVA precipitation) for the location of the basin determined from figure 22 or 23 (24-25).

2. Use the depth-duration relation from figure 41 (fig. 37-40 for TVA precipitation) to obtain durational 1-mi^2 values.

3. Determine the respective adjustment percentages for 10, 50 and 100 mi^2 from figure 26.

4. Multiply step 3 times step 2 to obtain PMP (TVA precipitation) for 1, 10, 50, and 100 mi^2.

5. Plot values from step 4 on semi-log paper (area-log vs. depth-arithmetic scale) and smooth appropriately to obtain depth-area-duration values for area sizes between 1 and 100 mi^2 at the basin location.

Step

(Large-basin DAD)

5. Figure 52 (53) gives depth-area-duration relations for nonorographic PMP (TVA precipitation) at Knoxville Airport for storm areas between 100 and 3,000 mi^2, extrapolated to 5,000 mi^2 (dashed). From figure 54 or 55, determine the adjustment for the location of the subject drainage. Multiply the relations in figure 52 (53) by the adjustment from figures 54 and 55 to obtain storm averaged depth-area-duration relations applicable to the location of the drainage.

6. Determine the applicable TSF and/or BOF to obtain the TAF for 100 mi^2 from the procedure outlined in section 5.4.3.

7. Multiply the DAD relations from step 5 by the TAF from step 6 to obtain terrain adjusted DAD for all areas $\geq$100 mi^2.

8. Plot the DAD relations in steps 4 and 7 and observe the degree of agreement at 100 mi^2. Subjectively, smooth the relations across the interface (100 mi^2) to effect the least change to either set of original relations, yet maintain relations that are parallel or somewhat converging with increasing area. It is not expected that smoothing will influence relations for areas greater than 500 mi^2.

5.4.1 Western Basins

The following steps are necessary to determine the isohyetal values and are taken from HMR No. 52 (Hansen et al. 1982).

Step

1. Place the idealized isohyetal pattern from figure 72 over the drainage with an orientation such as to place the maximum volume of precipitation in the drainage. This is generally accomplished by fitting the greatest number of whole isohyets within the drainage outline.

2. Select from the DAD curves established in section 5.4 step 8 a set of standard storm area* sizes both smaller and larger than the drainage area (up to 3 or 4 on either side) and read off the values.

3. Obtain incremental differences for each of the first three 6-hr periods (0 to 6, 6 to 12, 12 to 18 hr) through successive subtraction for each area size considered in step 2. Plot the 6-hr incremental values on semi-log paper. Smooth the data such that the incremental rainfall amounts decrease or remain constant with increases in both duration and pattern area size. In drawing the smoothing curves, choose a scale for the abscissa (incremental depths) that allows values to be read off to the nearest hundredth. This is a computational device and does not indicate data are accurate to hundredths of an inch.

4. Given the placement of the isohyetal pattern that best fits the basin, and for basins >300 mi^2 only, determine the orientation (to the nearest whole degree) of the major axis of the pattern in terms of degrees from north. If this orientation does not fall between 135° and 315°, add 180° so that it does.

5. Determine the orientation preferred for PMP conditions at this location from figure 73. If the difference between orientations from steps 4 and 5 is less than or equal to 40°, then for the isohyetal pattern as placed over the drainage there is no reduction factor to consider. One can proceed to step 7, otherwise proceed to step 6.

6. When the orientation difference in step 5 is greater than 40°, determine the appropriate adjustment factors for the isohyets involved, from the model shown in figure 74 (read to tenths of percent e.g., 93.3). Note that the amount of reduction is dependent upon area size (only pattern areas larger than 300 mi^2 need to be reduced) and the difference between

*The standard isohyet area sizes are: 10, 25, 50, 100, 175, 300, 450, 700, 1,000 1,500 2,150, 3,000, 4,500, 6,500, 10,000, 15,000, 25,000, 40,000 and 60,000 mi^2 (sect. 4.2.1).

orientations. Multiply the factor from figure 74 times the corresponding 6-hr incremental amounts from step 3 for each pattern area size to obtain incremental values reduced for pattern orientation.

7. Determine the maximum volume of precipitation for the three largest 6-hr incremental periods resulting from placement of the pattern over the drainage. To do this, it is necessary to obtain the value to be assigned to each isohyet in the pattern that occurs over the drainage during each period. Guidance for determining the maximum volume is given in the following steps related to the format in figure 80. It is suggested that an ample number of copies of this figure be reproduced to serve in the computation procedure.

   Start by determining the maximum volume for the 1st 6-hr incremental period.

   a. Fill in the name of the drainage, drainage area, date of computation, and increment (either 1st, 2nd, or 3rd) in the appropriate boxes at top of form (fig. 80).

   b. Put the storm area size (mi^2) from step 2 for which the first computation is to be made under the heading at the upper left of form. After completion of computations for this area, use the second storm area from step 3 and so on, until all area sizes have been evaluated.

   c. Column I contains a list of isohyet percentages. Use only as many isohyets as needed to cover the drainage.

   d. For the storm area size in step 7b, list in column II the corresponding percentages read from table 12 (first 6-hr period) for those isohyets needed to cover the drainage; use table 13 and table 14 for the 2nd and 3rd 6-hr periods, respectively, when determining step 7.

   e. Under the heading amount (Amt.) in column III, place the incremental average depth that results from step 5 or 6 corresponding to storm area size and increment of computation. Multiply each of the percentages in column II by the Amt. at the head of column III to fill column III.

   f. Column IV represents the average depth between adjacent isohyets. The average depth of the "A " isohyet is taken to be the "A" value from column III. The average depth between all other isohyets which are totally enclosed by the drainage is the arithmetic average of paired values in column III. For incomplete isohyets covering portions of the drainage, a weighted estimate of the average depth is recommended if a portion of the drainage extends beyond a particular isohyet. The average depth for the extended portion of the drainage may be taken as between 0.5 and

Increment:________

Drainage:______________________________ Area:__________ Date:__________

Area size	I Iso.	II Nomo.	III Amt.	IV Avg. depth	V ΔA	VI ΔV
	A					
	B					
	C					
	D					
	E					
	F					
	G					
	H					
	I					
	J					
	K					
	L					
	M					
	N					
	O					
	P					
				Sum =		

Area size	I Iso.	II Nomo.	III Amt.	IV Avg. depth	V ΔA	VI ΔV
	A					
	B					
	C					
	D					
	E					
	F					
	G					
	H					
	I					
	J					
	K					
	L					
	M					
	N					
	O					
	P					
				Sum =		

Area size		Amt.	
	A		
	B		
	C		
	D		
	E		
	F		
	G		
	H		
	I		
	J		
	K		
	L		
	M		
	N		
	O		
	P		
			Sum =

Area size		Amt.	
	A		
	B		
	C		
	D		
	E		
	F		
	G		
	H		
	I		
	J		
	K		
	L		
	M		
	N		
	O		
	P		
			Sum =

Figure 80.--Example of computation sheet showing typical format. See text for clarification and instructions for completing this form (Continued).

1.0 times the difference between the enclosing isohyets plus the lower isohyet. The weighting relation is given by:

$$F(X-Y) + Y$$

where X and Y are adjacent isohyet values (X>Y), and the weight factor, F, is between 0.5 and 1.0. If only a small portion of the drainage extends beyond X, then the weight factor may be taken closer to 1.0, and if the drainage extends nearly to Y, then a weight factor close to 0.5 is appropriate.

g. Column V lists the incremental areas between adjacent isohyets. For the isohyets enclosed by the drainage, the incremental area can be obtained from the 3rd column in table 11. For all other isohyets it will be necessary to planimeter the area of the drainage enclosed by each isohyet and make the appropriate successive subtractions. The sum of all the incremental areas in column V should equal the area of the drainage. It is important to note that if the computation in step 7e results in the zero isohyet's crossing the drainage, the appropriate total area is that contained within the zero isohyet, and not the total drainage area.

h. Column VI gives the incremental volume obtained by multiplying corresponding values in column IV times those in column V. The incremental volumes are summed to obtain the total volume of precipitation in the drainage for the specified pattern area size for that 6-hr period.

i. Steps 7b to 7h are repeated for all the other pattern area sizes elected in step 7b.

j. The storm area size from step 7b that results in the largest of the volumes obtained in steps h and i represents the preliminary maximum volume for the 1st 6-hr incremental period and specifies the storm area to which such volume relates. The area of maximum volume can be used as guidance in choosing pattern areas to compute volumes for the 2nd and 3rd 6-hr incremental period. Presumably, this guidance narrows in on the range of pattern area sizes considered and possibly reduces in some degree the number of computations. Compute the 2nd and 3rd 6-hr incremental volumes by repeating steps 7a to 7i, using the appropriate tables to obtain isohyet labels.

k. Sum the volumes from steps 7h to 7j at corresponding pattern area sizes and plot the results in terms of volume vs. area size (semi-log plot). Draw a smooth curve through the points to determine the area size that gives the maximum 18-hr volume in the drainage.

m. It is recommended, although not always necessary, that the user repeat steps 7b through 7k for one or two supplemental area sizes (area sizes other than those of the standard isohyetal pattern given in step 2) on either side of the area size of maximum volume in step 7k. This provides a check on the possibility that the maximum volume occurs between two of the standard isohyet area sizes. To make this check, an isohyet needs to be drawn for each supplemental area size in the initial isohyetal pattern positioned on the drainage, so that the corresponding incremental areas between isohyets can be determined (planimetered). In addition, supplemental cusp points need to be determined in figures 75, 76 and 77* for each of the area sizes considered. To find the appropriate cusp position, enter the ordinate at the supplemental area size and move horizontally to intersect a line between the two most adjacent cusps. This intermediate point will be the percentage for the supplemental isohyet when reading the other isohyet percentages in step 7d; otherwise follow the computational procedures outlined in steps 7a to 7k.

n. The largest 18-hr volume obtained from either step 7k or 7m then determines the final PMP storm area size for the pattern placement chosen.

8. Determine the areal distribution of PMP storm-area averaged depth over the basin (see note, sect. 4.3.2). This is accomplished in the following steps:

   a. For the area size determined for the PMP storm in step 7n, use the data in step 2 and draw a depth-duration curve out to 72 hr and read off values from the smoothed curve for each 6 hr (6 to 72 hr).

   b. Obtain 6-hr incremental amounts for the data in step 8a for the 4th through 12th 6-hr periods in accordance with step 3, and follow procedural step 5 to adjust these incremental values for isohyetal orientation, if needed.

   c. Steps 8a and 8b give incremental average depths for each of the twelve 6-hr periods in the 72-hr storm. To obtain the values for the isohyets that cover the drainage, multiply the 1st 6-hr incremental depth by the 1st 6-hr percentages obtained from table 12, or from the nomogram (fig. 75) for the area size determined in step 7n. Then multiply the second 6-hr incremental depth by the second 6-hr percentages from table 13, or from the nomogram (fig. 76), for the same area size, and similarly for the third 6-hr increment (table 14, or fig. 77). Finally,

*These figures represent nomograms used to obtain the data provided in tables 12, 13 and 14.

multiply the fourth through 12th 6-hr incremental depth by the percentages in table 15, or from the nomogram (fig. 78). As a result of this step, a matrix of the following form can be completed (to the extent of whichever isohyets cover the drainage). This provides the areal distribution for basins in the western TVA region. If after obtaining PMP values TVA precipitation isohyetal values are desired, then it is unnecessary to start over by recomputing DAD curves from figure 53 for TVA precipitation. Instead, TVA precipitation can be obtained directly from PMP by multiplying the PMP label values by 0.58, 0.55 or 0.53 depending on whether the majority of the basin is considered as "rough," "intermediate," or "smooth," respectively.

Isohyet	6-hr Increment											
(in.)	1	2	3	4	5	6	7	8	9	10	11	12
A												
B												
C												
.												
.					Isohyet Values (in.)							
.												
etc.												

In the event that concurrent basins are of interest for a basin in the west, go to the procedures outlined in section 5.4.4.1, otherwise continue here.

d. To obtain incremental basin-average depths for the drainage, compute the volumes for each 6-hr increment for the storm area size of the PMP pattern determined in step 7j. Divide each incremental volume by the drainage area covered by precipitation.

If one compares the basin-averaged depth obtained in this step with the storm-averaged depth for the basin area from the DAD curves in step 5, section 5.4, generally the former will be less. This reduction represents the adjustment to total storm precipitation that occurs because of orientation (if $\geq 40°$ from the preferred orientation) and because of factors related to the irregular shape of the drainage.

5.4.2 Eastern Basins

In the eastern region, it is first necessary to establish the total PMP basin-centered storm pattern as in section 5.4.1, and then adjust this pattern to include the effects of terrain, as described in the following steps. Note that when applying this procedure to small basins (<100 mi^2), only steps 1, 5, 7, and 8 are to be used for both PMP and TVA precipitation.

Step

1. Determine the basin-centered isohyetal pattern placement and isohyet values as described in section 5.4.1 steps 1 to 8c. Determine the volume representing terrain adjusted total PMP for the basin, designated as V_x.

2. Adjust the nonorographic elliptical pattern from its basin-centered position in step 1 to reflect the broadscale effects of terrain (sect. 4.3.2) by moving the pattern toward the location of the maximum 2-yr 24-hr amount within the basin (fig. 59). Note that if peak discharge is critical, other placements may be considered in a series of trials to determine the location that results in maximum discharge. Keep the displaced center of the pattern at least 10 mi inside the basin boundary.

3. If concurrent basins are of interest go to section 5.4.4.2, otherwise to step 4 for the primary basin (one for which PMP is determined).

4. Determine the volume of precipitation within the primary basin by planimetering the displaced pattern in step 2. Adjust the isohyet values by the ratio of the basin-centered volume to the displaced volume for each 6-hr increment, in order to maintain the same volume as in the basin-centered position.

5. Calculate the basin warping factor, W. W is the inverse of the area-averaged 2-yr 24-hr precipitation field covering the basin (expressed as a percentage). W will be used in step 8 to maintain the same volume in the warped pattern as in the basin-averaged elliptical pattern. To convert the 2-yr 24-hr analysis to a percentage analysis, determine the 2-yr 24-hr value at the center of the displaced elliptical pattern. This value is set at 100 percent and the remainder of the 2-yr 24-hr analysis is expressed as a percentage of this central value.

6. Graphically multiply the adjusted isohyet values in step 4 by the 2-yr 24-hr percental analysis from step 5 to reflect the local terrain influence on the pattern. Make these calculations either at points of intersection between the two patterns, or on some uniform grid network that yields acceptable detail. Supplemental points may be necessary to verify some regions of non-uniform gradient.

7. Analyze the resulting product from step 6 to derive the terrain adjusted (warped) isohyetal pattern for the basin. Adjust the isohyet values in this step to maintain the volume established for V_x in step 1. However, rather than planimeter the pattern, it is only necessary to multiply the isohyets by the warping correction factor, W, from step 5. The resulting pattern and isohyet values represent the terrain adjusted total PMP or TVA precipitation for the basin.

5.4.3. Computation of Terrain Adjustments

This section covers the determination of terrain factors for the three basic regions of the Tennessee River Valley; the west, the nonmountainous east, and the mountainous east (refer to fig. 1). If concurrent basins are of interest, reference should be made to section 5.4.4. The following steps provide the procedures for obtaining the TSF (terrain stimulation factor), BOF (broadscale orographic factor), and TAF (total adjustment factor) for the PMP and TVA storm patterns.

5.4.3.1 Western and Nonmountainous Eastern Regions.

Step

1. From figures 67 and 68, determine the percentage of the basin influenced by intermediate and rough terrain.

2. Use figure 65 to get the adjustment for each percentage in step 1 and add the two adjustments.

3. Since the adjustments from figure 65 are for 100 mi^2, it is necessary to reduce these to the area size of the basin by the percentage obtained from figure 66, based on the entire basin area. The product is the terrain stimulation factor, TSF, to which 1.0 must be added to make this a positive factor (to increase the total precipitation). The BOF is 0 in these regions. Therefore, the total adjustment factor, TAF, is in fact the TSF. Round the TAF to the nearest 5 percent. Return to the next step in the computation procedure.

5.4.3.2 Mountainous East Region.

Step

1. By definition, all the mountainous east region is considered rough. Therefore, from figure 65, the TSF is 16 percent for a basin area of 100 mi^2.

2. From figure 66, obtain the percent adjustment to the TSF for area size of the basin. Multiply the adjustment times the 16 percent from step 1 to get the adjusted TSF for the basin. Add 1.00 to the TSF to make this a positive factor (to increase the total precipitation).

3. Determine the 6-hr 1-mi^2 average PMP from figure 23 for the basin. Divide this amount by 1.16, since the basin is entirely rough. This removes all the thunderstorm-induced terrain effect in the basin.

4. Multiply step 3 times step 2.

5. The nonorographic smooth 1-mi^2 PMP at 6 hr from figure 16 is 34.4 in. Locate the basin on figure 69 and read the percentage reduction caused by the sheltering effect of the mountains.

Multiply the 34.4 in. by the reduction factor (1.0 minus the amount from fig. 69).

6. Divide step 4 by step 5 to get the percentage of orographic increase applicable to the drainage.

7. From figure 63, determine the optimum wind flow direction applicable to the largest percentage of the basin covered by one of the possible directions.

8. For the percentage in step 7, use figure 64 to obtain the orographic adjustment for optimum wind direction.

9. Multiply step 8 times step 6 to obtain the orographically modified TSF.

10. Use figure 14 to determine the percentage of the basin covered by primary upslopes, secondary upslopes, and sheltered regions. Multiply these percentages by 0.55, 0.10 and 0.05, respectively (sect. 3.4.1). Add the results and round off to the nearest 0.05 to obtain the broadscale orographic factor, BOF. (Note: If BOF is for a basin whose area is between 100 and 110 mi^2, figure 70 should be used to adjust BOF.)

11. Add the BOF of step 10 to the modified TSF of step 9 to get the total adjustment factor, TAF. Round to nearest 5 percent. Return to the next step in the computation procedure.

5.4.3.3 Basins Partially in Two or More Regions. Some basins in the Tennessee River watershed may not be located entirely in the nonmountainous east, or entirely in the mountainous east, or in the west regions. In these situations neither the computation of the nonorographic PMP (TVA precipitation) nor the computation of the broadscale orographic factors (mountainous east only) is affected. It is only necessary to modify somewhat the procedure for computing the terrain stimulation factor, TSF. There are five steps needed in making the modification.

<u>Step</u>

1. Delineate the boundaries between all pertinent regions, and determine the percent of total basin area covered by each region.

2. Compute the TSF for each regional portion of the basin separately according to the procedures outlined in sections 5.4.3.1 (steps 1 to 3) and 5.4.3.2 (steps 1 to 9).

3. Weight the various TSF's in step 2 by the respective percentages determined in step 1 to obtain a total-basin TSF.

4. If one of the regions is the mountainous east, compute the BOF for that portion of the total drainage as described in section 5.4.3.2 (step 10).

5. Add the results obtained from step 3 and step 4 to obtain the TAF for the total basin. Round to the nearest 5 percent.

As an example, suppose that 80 percent of a particular basin is within the mountainous east and the TSF and BOF for that part of the basin is 1.10 and 0.05 percent, respectively. At the same time, the remaining 20 percent of the basin, in the nonmountainous east, has a TSF of 1.05 percent. Then the TSF for the entire basin is the weighted average, or 0.80 (1.10) plus 0.20 (1.05) = 1.09. Combining this 1.09 and the BOF of 0.05, gives a TAF for the entire basin of 1.14, rounded to the nearest 5 percent, or 1.15. Return to the next step in the computation procedure.

5.4.4 Computation for Concurrent Basins

Candidate concurrent basins are those for which basin-averaged nonorographic precipitation amounts of 0.1 in. or more occur in any 6-hr increment.

5.4.4.1 Western Basins. In the western region, if concurrent basins are of interest, the isohyetal total PMP pattern centered as in section 5.4.1 step 1 and having the isohyet percentages from section 5.4.1 step 8c needs to be expanded to cover the additional basins. The following steps need be considered before basin-averaged depths can be obtained for the individual basins.

Step

1. Determine the total area size of the primary and concurrent basins of interest in your application.

2. Determine the terrain stimulation factor, TSF, for each concurrent basin according to section 5.4.3. Apply the areal adjustment factor from figure 66 for the combined area from step 1 to each concurrent TSF. If the combined area exceeds 500 mi^2, the areal adjustment factor will be 0.25.

3. Adjust the TSF of each concurrent basin by dividing that TSF by the TSF of the primary basin.

4. Multiply the isohyet analysis labels within each basin by the respective adjusted TSF from step 3 to obtain the terrain adjusted isohyets. This step will produce a total isohyetal pattern with discontinuities at the border of each basin.

5. Changes to the isohyet analysis in the PMP basin should be held to a minimum, thus the recommendation is to make adjustments mostly in concurrent basins by smoothing across the discontinuities.

6. Basin-average depths for a concurrent basin are then determined by planimetering the portion of the pattern covering the basin to get the volume, and dividing by the basin area, as is done for the PMP basin in section 5.4.1 steps 8d and e.

5.4.4.2 Eastern Basins. In the eastern region, the displaced isohyetal pattern from section 5.4.2 step 2 is expanded to cover the concurrent basins. The following steps need to be considered before basin-averaged depths can be obtained for individual basin.

Step

1. Primary and concurrent basins may be in either the nonmountainous or mountainous east, or both. For those in the nonmountainous east, determine the TSF from section 5.4.3.1. For those in the nonmountainous east, determine the TAF from section 5.4.3.2. Adjust the concurrent basin TSF's or TAF's by the areal factor from figure 66 for the combined area of the primary plus concurrent basins being considered. Note the areal factor will be 0.25 for all combined areas greater than 500 mi^2.

   Adjust the TSF or TAF of each concurrent basin by dividing by the respective TSF or TAF of the primary basin (based on its location).

2. Calculate the warping factor, W, for the primary basin and each concurrent basin. W is the inverse of the basin-averaged 2-yr 24-hr precipitation analysis (expressed as a percentage). This requires that the 2-yr 24-hr analysis in figure 59 be converted to a percentage analysis based on the 2-yr 24-hr value at the center of the displaced elliptical pattern. The W determined for each basin is likely to be different.

3. Determine the volume of precipitation within the primary basin by planimetering the displaced pattern. Adjust the isohyet values by the ratio of the displaced pattern volume to the pattern volume at the basin-centered position. Do not adjust concurrent basins by this volume ratio. This will result in discontinuities at all boundaries between concurrent and primary basins.

4. Multiply the adjusted isohyets in step 3 by the appropriate adjusted TSF or TAF from step 1 for each concurrent basin. This step will result in discontinuous isohyets at the border of each basin. Planimeter the resulting isohyets of total PMP to determine the new volume representing terrain adjusted basin-averaged total PMP, designated as V_x for each basin.

5. Graphically multiply the adjusted isohyet labels in step 4 by the 2-yr 24-hr percental analysis from step 2 to reflect the local terrain influence on the pattern. Make these calculations either at points of intersection between the two patterns or on some uniform grid network that yields acceptable detail. Supplemental points may be necessary to verify some regions of non-uniform gradient.

6. Analyze the results from step 5 to derive the terrain adjusted (warped) isohyetal pattern. At this time, it is possible to smooth across the borders to eliminate the discontinuities resulting from step 4, although a smooth isohyetal pattern is not required by this procedure. Adjust each isohyet value to maintain the respective volume, V_x, for each basin in step 4.

To make this adjustment, multiply the isohyets in each basin by the respective warping correction factor, W, for that basin (step 2). The resulting pattern and isohyet value represent the terrain adjusted basin-averaged total PMP for the primary basin and concurrent basins of interest.

7. In order to obtain the areal distribution of TVA precipitation, multiply the smooth PMP isohyet labels obtained in step 6 by an appropriate adjustment factor. This factor is 0.58 (rough), or 0.55 (intermediate). In the mountainous east, all basins are rough and the 0.58 factor applies.

5.4.5 Cautionary Remarks

The procedures outlined in the previous sections are complex. During the development and evaluation of these procedures, it has become apparent that it is not possible to anticipate all possible uses to which these methods will be applied. Nevertheless, in our attempts to understand and control the outcomes that may occur, there appears to be at least two areas where it will be necessary to make comparisons before the results can be accepted. The first involves PMP for small areas (<100 mi^2). When determining the areal distribution for a relatively large drainage (>500 mi^2), particularly in an orographic region, one should compare the average depths for small areas in the large-scale pattern against comparable PMP estimates for that same location from the small-basin study (chapt. 2). The results from the small-area procedure should always equal or exceed results obtained as part of a large-area pattern distribution. In the event that PMP from the small-area PMP procedure in Chapter 2 is exceeded in such a comparison, the large-area storm isohyets are to be reduced proportionately so that the maximum value equals the small-area isohyet value. Excess volume that derives from this reduction is to be distributed throughout the remainder of the pattern within the drainage.

This comparison for small-basin PMP should always be made and is not particularly difficult or time consuming to do. Although we do not know how likely it is that this comparison will reveal problems (those instances when the portion of the large-pattern area averaged values for 100 mi^2 or less exceed comparable values from the small-area procedure), we expect that in most cases any exceedance will be small, and may be the result of incorrect planimetering or other form of calculation error. No redistribution of volume excess should be considered until all calculation steps have been confirmed.

The second comparison is somewhat more difficult, although it is expected that the number of occurrences for making it may be less than the first comparison discussed above. This comparison is as follows: for any large drainage that contains subdrainages, the area average depths of rainfall for individual subdrainages, based on the computation of spatially-distributed PMP for the total drainage, needs to be compared against areal average depths from PMP developed specifically for the subdrainages. That is to say, the site-specific PMP estimate for any subdrainage should exceed any areal average amount derived from a portion of a pattern used to spatially distribute PMP determined for a larger drainage that contains the subdrainage(s).

Again, in the complex procedures outlined in this study, a number of adjustment factors are used in the orographic and areal distribution steps. It is not possible to anticipate all the possible combinations of these factors, and it is conceivable that on occasion there may result a situation wherein the results obtained for a partial pattern over a subdrainage may exceed the site-specific PMP estimate for that subdrainage. The only subdrainage that needs to be compared to the one or more that may make up a large drainage is the one that contains the major portion of the pattern center. Therefore, if such an exceedance is discovered, a redistribution of precipitation must be made. As guidance in making this redistribution, it is recommended that the isohyets of the large drainage pattern be reduced proportionately to the degree necessary to match the area-averaged depths from the site-specific PMP. A volume of precipitation equal to the excess needs to be distributed throughout the remaining subdrainages of the large drainage. In all likelihood, the addition of these excess quantities to other subdrainages will not cause them, in turn, to exceed their site-specific PMP estimates.

In line with this comparison is the fact that table 22 in chapter 6 provides storm-averaged site-specific PMP for 26 basins. Thus, when any of these drainages are contained in larger drainages for which PMP is determined, the process to compare results is somewhat simplified. However, there are uncountable drainages within the Tennessee Valley that have not been evaluated for PMP using procedures in this report. The comparison process mentioned above requires that when large-basin PMP is determined, it is also necessary to consider and compare site-specific PMP estimates for some subdrainages. This additional burden of effort can be considerable, and the authors expect that with time and experience some guidance will be developed by users to indicate when such comparisons are necessary.

5.5 Examples of Computations

As pointed out in the introduction to this chapter, because of the five major options considered in this study, there are numerous possible combinations that may be of interest. Examples of such combinations are: small-basin TVA precipitation for a basin in the nonmountainous east, areal distribution of PMP for a basin in the western region, areally distributed PMP for a basin and the precipitation for concurrent drainages in the mountainous east. Since it would be difficult to present examples for all combinations that might be considered, this section provides a few selected examples that are believed representative. As such, it is hoped they will provide guidance to the computational process needed for any other possible consideration of interest.

5.5.1 PMP for a Small Basin

Take as an example a hypothetical 50-mi^2 basin in the orographically controlled upper Hiwassee drainage (see fig. 82 for basin outline). Following are details of the PMP computation, according to the steps outlined in section 5.2.1.

<u>Step</u>

1. Placement of the drainage outline (not shown) over figure 23 permits determination of a storm-averaged 6-hr 1-mi^2 PMP of 38.6 in. (chosen arbitrarily for this example).

2. Depth-durational values from 1 to 24 hr from figure 41 for a 6-hr 1-mi^2 amount of 38.6 in. are:

Duration (hr)	1	2	3	4	5	6	12	18	24
PMP (in.)	18.5	26.0	30.2	33.9	36.5	38.6	43.6	45.9	47.8

3. Areal reduction percentages of the 1-mi^2 amount from figure 26 are:

Duration (hr)	1	2	3	4	5	6	12	18	24
Reduction factor (%)	64.0	70.0	72.2	73.1	73.9	74.3	76.2	77.5	78.2

which are multiplied times the values from step 2 to obtain:

50 mi^2 PMP (in.)	11.8	18.2	21.8	24.8	27.0	28.7	33.2	35.6	37.4

4. The values from step 3 may be plotted and a smooth line fit to the points. Assume for this example that the results in step 3 represent a smooth line and no further smoothing is required and the values in step 3 are the average PMP for the basin.

5. Successively subtract amounts in step 4 to obtain average incremental values.

Duration (hr)	1	2	3	4	5	6	12	18	24
50-mi^2 PMP (in.)	11.8	6.4	3.6	3.0	2.2	1.7	4.5	2.4	1.8

6. Select a time sequence from section 2.2.14 that provides the hydrologically most critical hydrograph. Since this example does not allow for determining critical hydrological combinations, one possible sequence is offered as an example.

   a. Hourly sequence of maximum 6-hr PMP,

      Example: 6, 5, 4, 3, 1, 2; where 1 refers to the highest hourly amount.

   b. 6-hr sequence of 24-hr storm,

      Example: 4, 2, 1, 3; where 1 refers to the highest 6-hr amount, or in terms of depths (in.), 1.8, 4.5, 28.7 and 2.4.

The example sequence in terms of incremental PMP values from step 5 is:

Temporal Sequence (hr from beginning of storm)		PMP increments (in.) a.		b.	
1-6				1.8	Sequence of 6-hr increments
7-12				4.5	
13	Hourly sequence of Max. 6 hr.	1.7	=	28.7	
14		2.2			
15		3.0			
16		3.6			
17		11.8			
18		6.4			
19-24				2.4	

5.5.2 Areal Distribution of PMP for a Small Basin

The example provided here follows the procedure outlined in section 5.4. No consideration is given in this example to concurrent drainages; see description in section 5.4.4 for guidance if needed. To determine the areal distribution and the basin-averaged PMP as described in the section 5.4, the following steps should be completed. The basin used in this section is the same basin described in section 5.5.1, namely the 50-mi^2 Hiwassee basin.

<u>Step</u> (for PMP)

(for small-basin procedure)

1. Storm-averaged 6-hr 1-mi^2 PMP for the location of the basin as described in section 5.5.1 is 38.6 in. from figure 23.

2. From figure 41 obtain for 38.6 in. at 1 mi^2,

Duration (hr)	1	6	12	18	24
PMP (in.)	18.8	38.6	43.4	45.8	47.8

3. From figure 26,

Area (mi^2)			Percent		
10	85.3	88.5	89.2	89.8	90.2
50	65.3	74.9	76.8	77.8	78.3
100	55.0	68.8	71.7	72.7	73.2

4. Step 3 times step 2,

Area (mi^2)			Inches		
10	16.0	34.2	38.7	41.1	43.1
50	12.3	28.9	33.3	35.6	37.4
100	10.3	26.6	31.1	33.3	35.0

(for large-basin procedure)

5. From figure 52, the PMP D-A-D values (in.) valid at Knoxville Airport are:

Area (mi^2)	Duration (hr) 6	12	18	24	48	72
100*	19.2	22.3	24.7	26.6	29.7	31.7
175*	18.3	21.3	23.8	25.6	28.7	30.6
200	17.9	21.0	23.4	25.2	28.3	30.2
300*	16.9	20.0	22.4	24.2	27.3	29.2
450*	15.8	18.8	21.2	23.0	26.1	28.0
500	15.5	18.6	20.9	22.7	25.8	27.8
700*	14.5	17.5	19.8	21.6	24.7	26.7
1000*	13.4	16.4	18.7	20.5	23.6	25.6
1500*	12.2	15.1	17.3	19.0	22.1	24.1
2150*	11.0	13.9	16.0	17.7	20.8	22.8
3000*	10.0	12.9	14.9	16.6	19.7	21.6
4500*	8.7	11.6	13.5	15.2	18.3	20.1
5000	8.4	11.2	13.2	14.9	18.0	19.8

*Standard area sizes

Regional adjustment factor from figure 55 is 103.5 percent.

Multiplying 103.5 percent times the Knoxville DAD data (up to 24 hr only) yields for some area sizes:

Area (mi^2)	Duration (hr) 6	12	18	24
3000	10.35	13.35	15.42	17.18
1000	13.87	16.97	19.35	21.22
500	16.04	19.25	21.63	23.49
200	18.53	21.74	24.22	26.08
100	19.87	23.08	25.56	27.53

6. Steps for TSF from section 5.4.3.2.

6-1. TSF is 16 percent for basin area of 100 mi^2

6-2. No adjustment for area size, therefore, TSF is 1.16

6-3. In order to obtain the average 6-hr 1-mi^2 PMP from figure 23 for a 100-mi^2 basin, place the isohyetal pattern from figure 72 over the 50-mi^2 Hiwassee basin. Place the pattern so as to include as many of the larger PMP isohyets as possible. From table 11, isohyet D encloses 100 mi^2 area. Therefore, for that portion of the isohyetal pattern that is included within isohyet D, obtain the average 6-hr 1-mi^2 PMP. For the Hiwassee basin, the average 6-hr 1-mi^2 PMP for that portion of the basin within isohyet D turns out to be 39.0 in.

$$\frac{39.0}{1.16} = 33.62 \text{ in.}$$

6-4. Since we are considering a 100-mi^2 basin, no adjustment is needed from figure 66 to adjust the 16 percent. Therefore, 33.62 X 1.16 = 39.0 in.

6-5. Smooth 6-hr 1-mi^2 PMP from figure 16 is 34.4 in. From figure 69, the sheltering effect is 2 percent and subtract from 1.00 to get a 98 percent reduction factor. Multiply 34.4 X 0.98 = 33.71 in.

6-6. $\frac{39.0}{33.7} = 1.16$ as orographic increase applicable to basin.

6-7. From figure 63, 100 percent of basin exposed to southwest winds.

6-8. Adjustment from figure 64 is 100 percent.

6-9. 1.00 X 1.16 = 1.16 for orographically modified TSF.

6-10. From figure 14, 100 percent of basin is located in sheltered area; thus, the BOF equation from section 3.4.1 takes the form:

BOF = 0 (0.55) + 0 (0.10) + 1.00 (0.05) = 0.05

Since the area size being considered for determining the TAF is 100 mi^2, it is necessary to refer to figure 70 for an additional adjustment of 0.50.

Therefore,
BOF = 0.05 X 0.5 = 0.025, which when rounded to nearest 0.05 gives:

BOF = 0.05

In this example the adjustment in figure 70 is ineffective, but its effect is substantial in situations where the basin is in the primary upslope region of figure 14.

6-11. TAF is now determined by adding the TSF (step 6-9) and the BOF (step 6-10), 1.16 + .05, respectively, to equal 1.21 rounded to the nearest 0.05 gives:

TAF = 1.20

7. Multiply 1.20 times the (regionally adjusted) depths (in.) in step 5, or

Pattern area (mi^2)	Duration (hr) 6	12	18	24
3000	12.4	16.0	18.5	20.6
1000	16.6	20.4	23.2	25.5
500	19.3	23.1	26.0	28.2
200	22.2	26.1	29.1	31.3
100	23.8	27.7	30.7	33.0

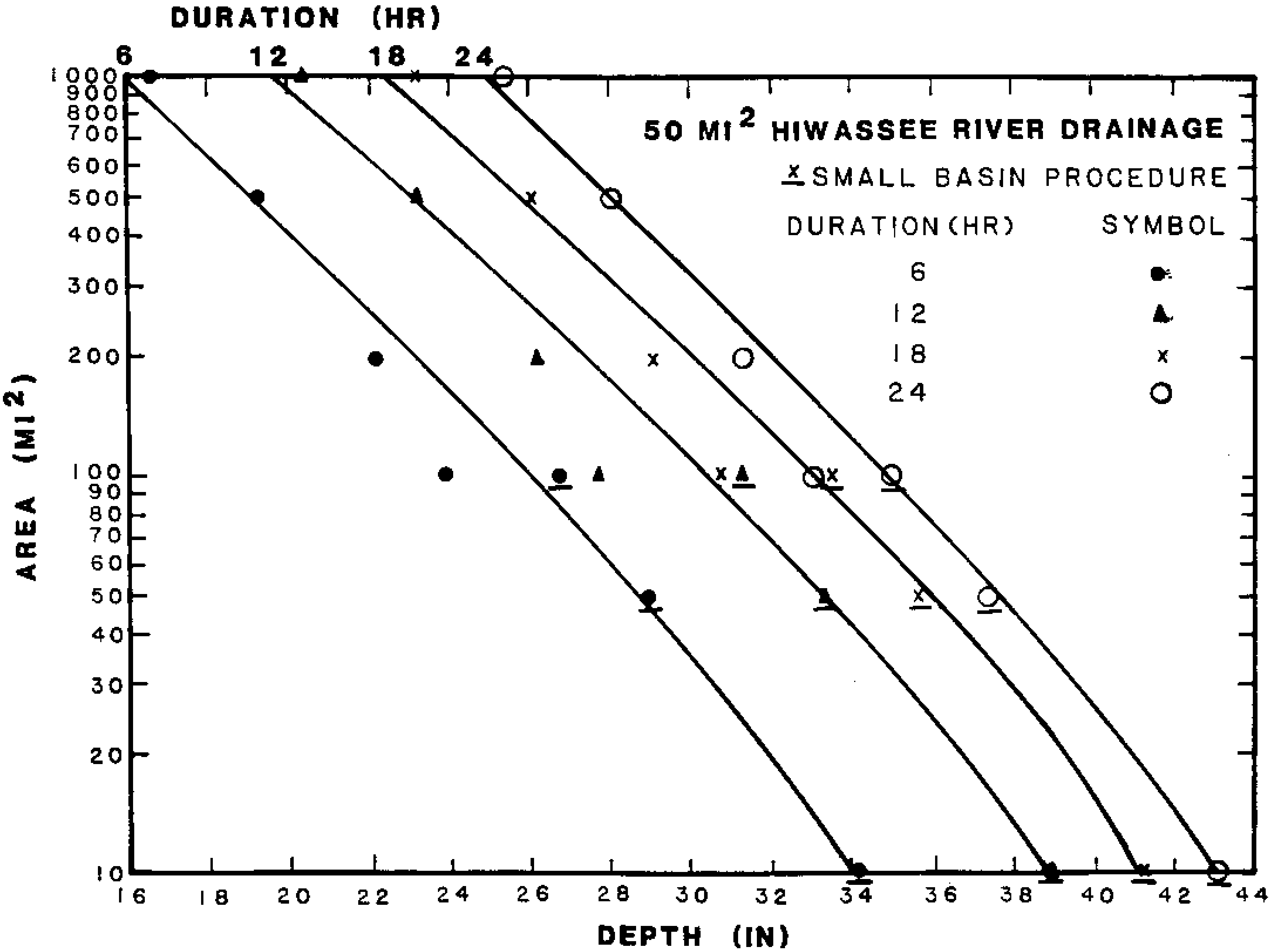


Figure 81.--DAD data valid for Hiwassee River drainage.

8. Data in step 4 and step 7 are plotted in figure 81. Note the two values plotted at 100 mi^2 - one depth obtained from the small basin procedure (steps 1-4) and the other depth from the large basin procedure (steps 1-7).

Areal distribution according to section 5.4.2. First refer to steps 1 to 8c in section 5.4.1 as follows:

1. Place the isohyetal pattern from figure 72 over the drainage as shown in figure 82 to obtain most complete isohyets within basin to provide maximum volume. The "C" isohyet is enclosed by the basin, while the "E" isohyet encloses the basin.

2. From figure 81, read off depth area values for selected standard area sizes (refer to footnote, page 129).

Pattern area (mi^2)	Duration (hr) 6	12	18	24
10	34.1	38.8	41.1	43.0
25	31.2	36.0	38.6	39.9
50	28.8	33.3	36.0	37.4
100	26.1	30.5	33.2	35.0
175	23.7	28.0	30.6	31.3
300	21.3	25.4	28.2	29.8
450	19.5	23.4	26.4	28.7
700	17.6	21.3	24.2	26.5

3. Incremental differences from step 2.

Pattern area (mi^2)	6-hr period 1	2	3
10	34.1	4.7	2.3
25	31.2	4.8	2.6
50	28.8	4.5	2.7
100	26.1	4.4	2.7
175	23.7	4.3	2.6
300	21.3	4.1	2.8
450	19.5	3.9	3.0
700	17.6	3.7	2.9

Plot these data (not shown) and "eye fit" smooth lines. Read comparable areal values from the smoothed lines. See section 5.4.1, step 3, for guidance in smoothing.

Pattern area (mi^2)	1	2	3
10	34.5	5.00	2.84
25	30.5	4.72	2.77
50	28.2	4.50	2.75
100	25.4	4.28	2.70
175	23.2	4.13	2.66
300	21.0	3.95	2.63
450	19.5	3.83	2.60
700	17.8	3.70	2.57

4. Since the basin is less than 300 mi^2, adjustment for isohyetal orientation is not considered in this example.

5. Not applicable.

6. Not applicable.

7. Determine the maximum volume of precipitation according to figure 80. From substeps a to j, we obtain the following results for volumetric water of three greatest 6-hr increments:

Pattern area (mi^2)	1	2	3	Total
10	1186.94	172.41	98.33	1457.68
25	1288.53	206.26	122.02	1616.81
50	1328.14	217.72	132.39	1678.25
100	1309.88	218.99	135.49	1664.36
175	1271.53	216.22	134.60	1622.45
300	1226.30	210.96	133.89	1571.15
450	1194.55	207.51	132.97	1535.02
700	1160.01	203.57	132.05	1495.63

From steps k to n and the above results, the maximum volume occurs for a storm pattern area of 50 mi^2. It is possible that by using supplementary isohyets, the maximum volume may occur at some non-standard area size; however, at these small areas, the effect of such additional accuracy is believed small and no such check has been made in this example.

8. These steps give the temporal distribution of storm-averaged PMP over the basin.

a.

Duration (hr)	6	12	18	24
PMP (in.)	28.2	32.7	35.4	37.4

(smoothed)

b.

6-hr increm.	1	2	3	4
PMP (in.)	28.2	4.5	2.8	2.0

c. Multiply each incremental amount in step b. times the respective index percents from tables 12, 13, 14, and 15. This gives the following incremental values for the isohyets covering the drainage.

	6-hr increment			
Isohyet	1	2	3	4
A	29.89	4.73	2.79	2.00
B	27.92	4.52	2.74	2.00
C	25.94	4.32	2.71	2.00
D	18.61	3.42	2.16	1.57
E	15.23	2.84	1.75	1.26

Concurrent precipitation is not considered in this example.

d. To obtain basin-averaged incremental depths, compute the volumes of the PMP for each 6-hr increment for the drainage by planimetering the isohyetal pattern from step c that occurs within the basin, and divide each incremental volume by the basin area.

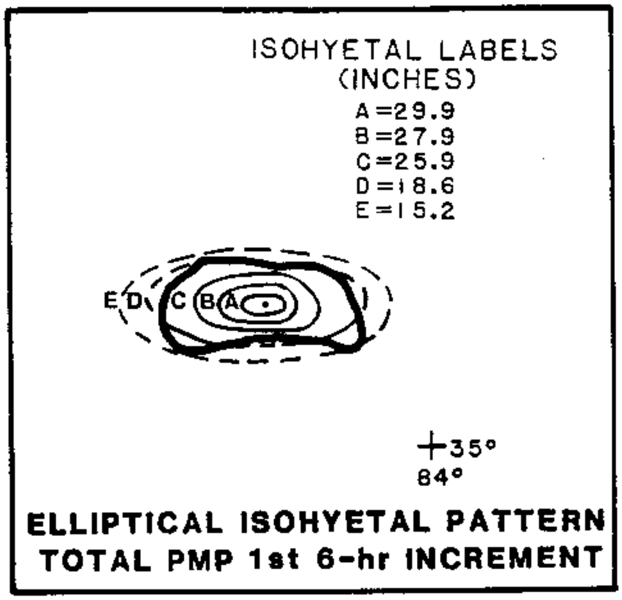


Figure 82.--Elliptical pattern centered over Hiwassee River drainage.

6-hr increm.	1	2	3	4
PMP (in.)	26.56	4.35	2.64	1.53

By summation of these incremental amounts, the basin-averaged total is 35.08 in. for 24-hr duration. This can be compared to the 24-hr storm-averaged PMP from step 8a of 37.4 in. for a reduction of a little more than 6 percent that is related to basin shape.

Return to step procedure of section 5.4.2, to determine the orographic modification to the elliptical pattern just obtained.

Step

1. See step 8c of previous section.

2-4. Not applicable.

5. Basin centered pattern in figure 82 is placed over the 2-yr 24-hr analysis in figure 59 and the pattern center determined to be 2.95 in. There is no lateral displacement for small basins (<100 mi^2). Convert the 2-yr 24-hr analysis covering the drainage to a percentage of the center value of 2.95 in. This is shown in figure 83.

6. Not applicable.

7. Multiply the isopercental analysis in figure 83 times the isohyetal values in figure 82 and analyzing the resulting values provides the degree of warping reflected in the 2-yr 24-hr analysis.

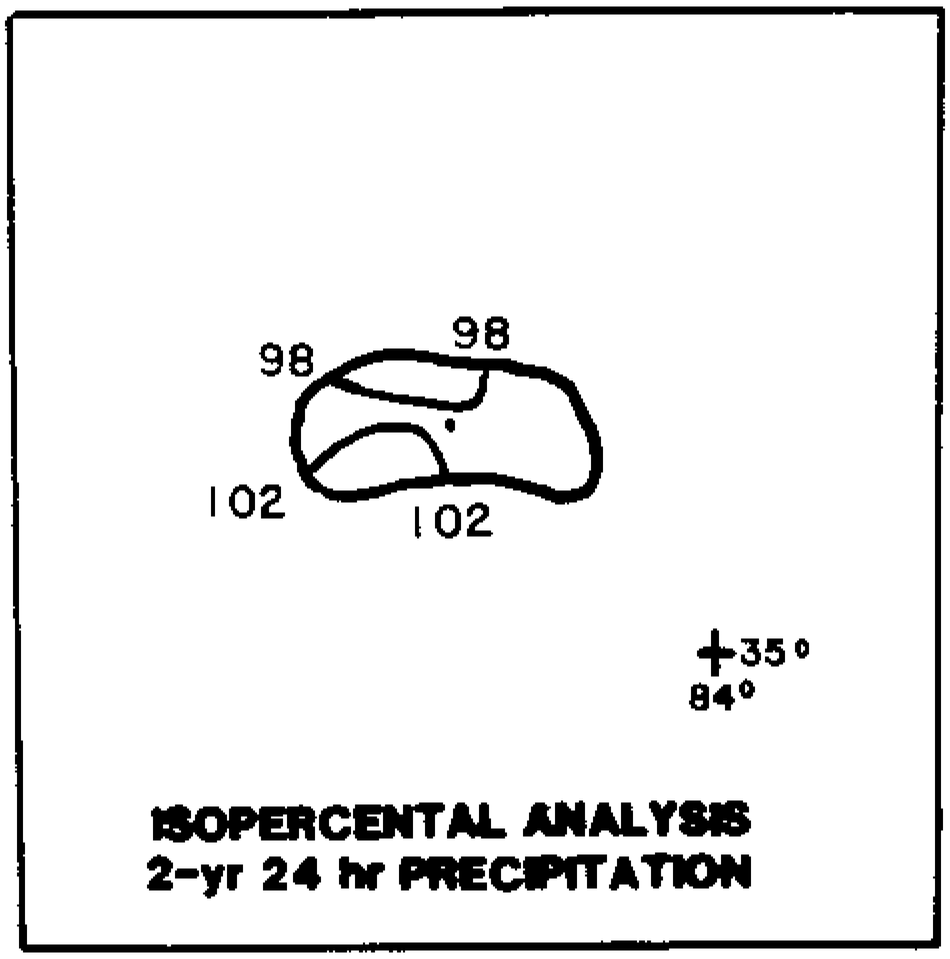


Figure 83.--Isopercental analysis of 2-yr 24-hr precipitation over the Hiwassee River drainage.

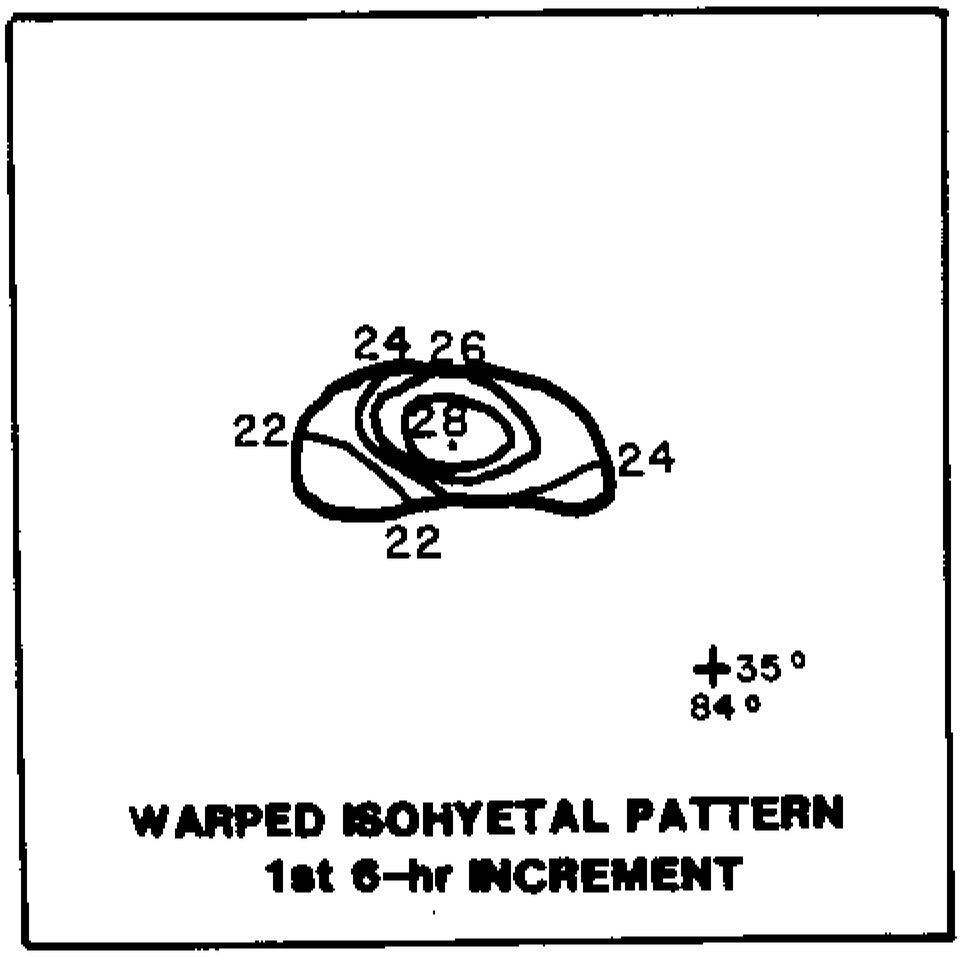


Figure 84.--Resulting isohyetal pattern of total PMP, 1st 6-hr increment for Hiwassee River drainage.

8. Planimeter the pattern as warped in step 7 to get the volume, V_x. The isohyetal values in the warped pattern (fig. 83) are then multiplied by the ratio of V_o/V_x, where V_o represents the volume from step 7 (page 207) in the areal computation of this example. This maintains the initial volume through the warping process, and the resulting pattern and isohyetal labels are shown in figure 84.

5.5.3 PMP and TVA precipitation for a large basin in the mountainous east.

The basin which is presented as an example for computing total PMP and TVA precipitation for a basin located in the mountainous east is the 295-mi^2 Little Tennessee River basin above Franklin, NC. This basin is subbasin 8 on figure 100

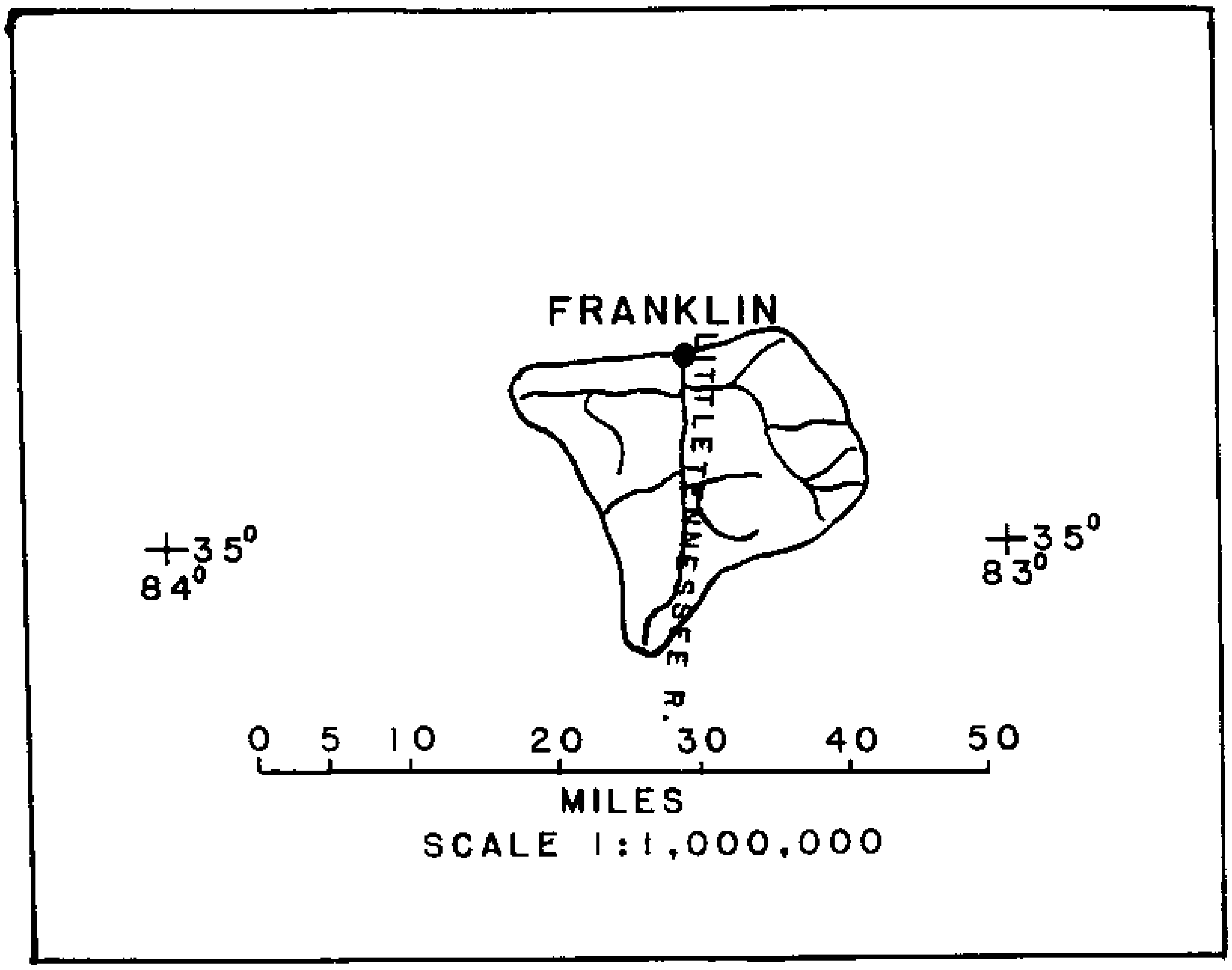


Figure 85.--Little Tennessee River basin (295 mi^2) above Franklin, NC showing drainage.

(chapt. 6), and is shown in figure 85. Individual steps for computing the total storm-averaged PMP and TVA precipitation follows the procedure outline in sections 5.3.1, 5.3.2, and 5.4.3.2. An example of areal distribution applied to this basin is presented in section 5.5.5.

Step (for PMP)

1. Scale 6-, 12-, 18-, 24-, 48-, and 72-hr storm-centered PMP depths for the area size of the basin (295 mi^2) from figure 52. These are storm-averaged nonorographic values applicable to Knoxville, TN.

Duration (hr)	6	12	18	24	48	72
PMP (in.)	16.8	19.9	22.2	24.1	27.2	29.2

2. From figure 55, read the regional adjustment percentage for the centroid of the drainage (35°05'N, 83°23'W), or 1.03.

3. Multiply step 2 times step 1,

Duration (hr	6	12	18	24	48	72
PMP (in.)	17.3	20.5	22.9	24.8	28.0	30.1

These are the storm-averaged nonorographic PMP values applicable for the 295-mi^2 drainage. Areal distribution of these depths will not be considered in this example (see sect. 5.5.5).

4. These values can be plotted on a depth-duration curve and a smooth curve fit to obtain complete 6-hr values (not done in this example).

5. Incremental depths are obtained through subtraction of successive 6-hr depths.

6-hr Increment (hr)	1	2	3	4	5-8	9-12
PMP (in.)	17.3	3.2	2.4	1.9	3.2	2.1

where the second 3.2 is the sum of the amounts for the 5th through 8th increments and the 2.1 is the sum of the amounts for the 9th through 12th increments.

6. Determine the TAF from section 5.4.3.2 for this basin in the mountainous east.

Step (for TAF, step sequence from sect. 5.4.3.2)

6-1. By definition, all basins in the mountainous east are rough. Therefore, the adjustment from figure 65 is 16 percent.

6-2. From figure 66, for a 295 mi^2, the adjustment is 42 percent. Therefore,

adjusted TSF = .16 X .42 = 0.067
add 1.0 to get a positive factor or 1.067

6-3. 6-hr 1-mi^2 PMP for basin from figure 23 = 40.3 in. Dividing 40.3 by 1.16 (since the basin is 100 percent rough) removes all of the thunderstorm induced terrain effect,

40.3/1.16 = 34.7

6-4. Multiplying step 6-3 times step 6-2,
34.7 x 1.067 = 37.0 in.

6-5. Nonorographic smooth 1-mi^2 PMP at 6 hr from figure 16 is 34.4 in. From figure 69 the reduction percentage due to sheltering is 2 percent. Multiply the reduction factor (1.0 - 0.02) = .98 times 34.4 to get 33.7 in.

6-6. Divide step 6-4 by step 6-5 to get the percentage orographic increase, or;

$$\frac{37.0}{33.7} = 1.10$$

6-7. The optimum wind from figure 63 is southerly, and 70 percent of the basin is exposed to winds from this direction.

6-8. From figure 64 for the percentage in step 6-7, we get a 95 percent orographic adjustment for optimum wind.

6-9. Multiply step 6-8 times step 6-6 to get the orographically modified TSF, or;

0.95 x 1.10 = 1.05

6-10. Figure 14 shows 50 percent of basin covered by primary upslopes, 30 percent covered by secondary upslopes, and 20 percent by sheltered areas. Multiply these percentages by 0.55, 0.10 and 0.05, respectively, and add to get the broadscale orographic factor, BOF;

0.50 x 0.55 = 0.275
0.30 x 0.10 = 0.030
0.20 x 0.05 = 0.010

BOF = 0.315 = 0.30 rounded to nearest 0.05. (Since the primary basin is 295 mi^2, there is no adjustment to BOF from figure 70).

6-11. BOF + TSF = TAF
0.30 + 1.05 = 1.35
(to nearest 5 percent.)

7. Multiply TAF from step 6-11 by the incremental values in step 5 to get the orographic and terrain adjusted incremental (storm-averaged) PMP for this basin,

6-hr increment (hr)	1	2	3	4	5-8	9-12
PMP (in.)	23.4	4.3	3.2	2.6	4.3	2.8

where the 4.3 is the sum of the amounts for the 5th through the 8th increments and the 2.8 is the sum of the amounts for the 9th through the 12th increments.

8.

Increment	1	2	3	4	5-8	9-12
PMP (in.)	23.4	27.7	30.9	33.5	37.8	40.6

where the 37.8-in. amount is the total after 8 increments and the 40.6 in. is the total after 12 increments.

When these values are plotted on a depth-duration curve smoothed values are obtained. The resulting values for subbasin 8 are shown in table 22.

In the event the TVA precipitation for a 72-hr TVA storm was of interest, the following procedures apply:

Step (for TVA precip., step sequence from sect. 5.3.2)

1. 72-hr storm

2. From step 8 of this example for total PMP at 72 hr, we get a value of 40.6 in.

3. From figure 68, the basin is totally rough by definition. Therefore, to convert the 72-hr or 24-hr PMP to 72-hr TVA or 24-hr TVA precipitation, it is necessary to use the 0.58 factor (rough basins) from section 2.2.7.1.

4. Multiply step 2 by step 3

   40.6 x 0.58 (for rough basins) = 23.5 in.

5. From figure 79 for the 72-hr TVA storm, and for a value of 23.5 in. we get the distribution of TVA precipitation, adjusted for terrain and orographic influence,

Duration (hr)	6	12	18	24	36	48	60	72
TVA precip. (in.)	8.6	13.3	16.2	18.2	20.3	21.7	23.0	23.5

   This example demonstrates the fact that in this study, if TVA precipitation is desired, it is often quicker to first compute the PMP estimate. The additional steps needed to compute PMP are not many and the steps to determine the terrain adjustment factor are also necessary for TVA precipitation.

5.5.4 Areal Distribution of PMP and TVA Precipitation for Large Basin in West

For this example, the Duck River above Columbia, TN (1,208 mi^2 centered at 35°34'N, 86°32'W) is chosen to demonstrate the computational procedure outlined in sections 5.3.1, 5.4.1 and 5.4.3.1. The basin outline is shown in figure 86.

Step (for PMP sect. 5.3.1)

1. Scale precipitation storm-centered depths for various durations and area sizes at Knoxville, TN (not shown) from figure 52.

2. The regional adjustment factor is obtained from figure 54 for the centroid of this basin, or 104.5 percent.

3. Multiply step 2 times step 1 to create a set of DAD curves applicable for the location of the basin. These are shown in figure 87 for the Duck River basin. From figure 87 storm-averaged nonorographic PMP can be obtained. This rainfall is obtained by reading off values from figure 87 for an area size of 1,208 mi^2.

	Duration (hr)											
PMP (in.)	6	12	18	24	30	36	42	48	54	60	66	72
1,208 mi^2	13.2	16.8	19.0	20.6	21.7	22.8	23.7	24.5	25.2	25.8	26.4	26.8

   However, for this example, it was decided that areal distribution of the PMP is of interest to obtain basin-averaged values.

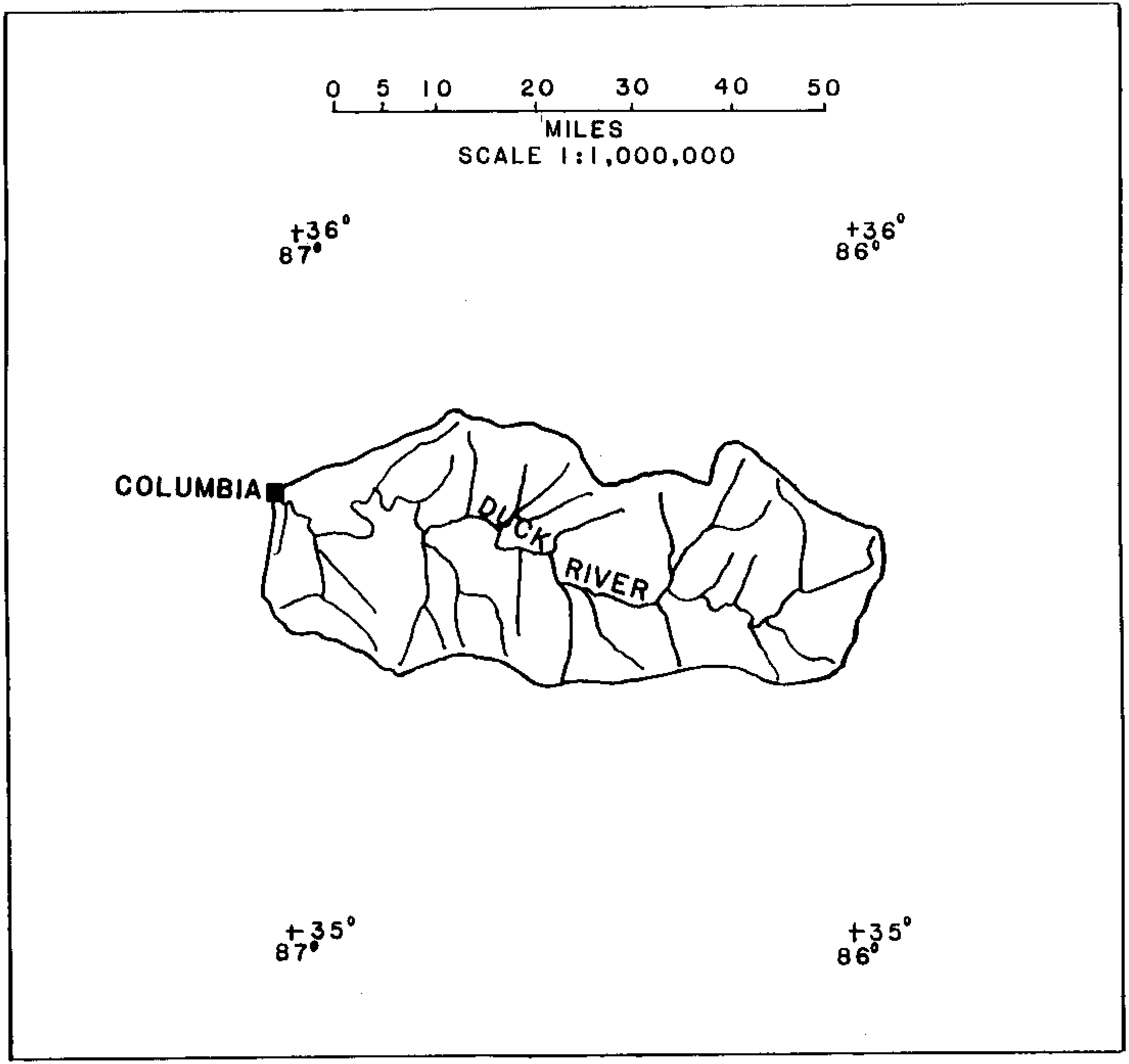


Figure 86.--Duck River drainage (1,208 mi^2) above Columbia, TN.

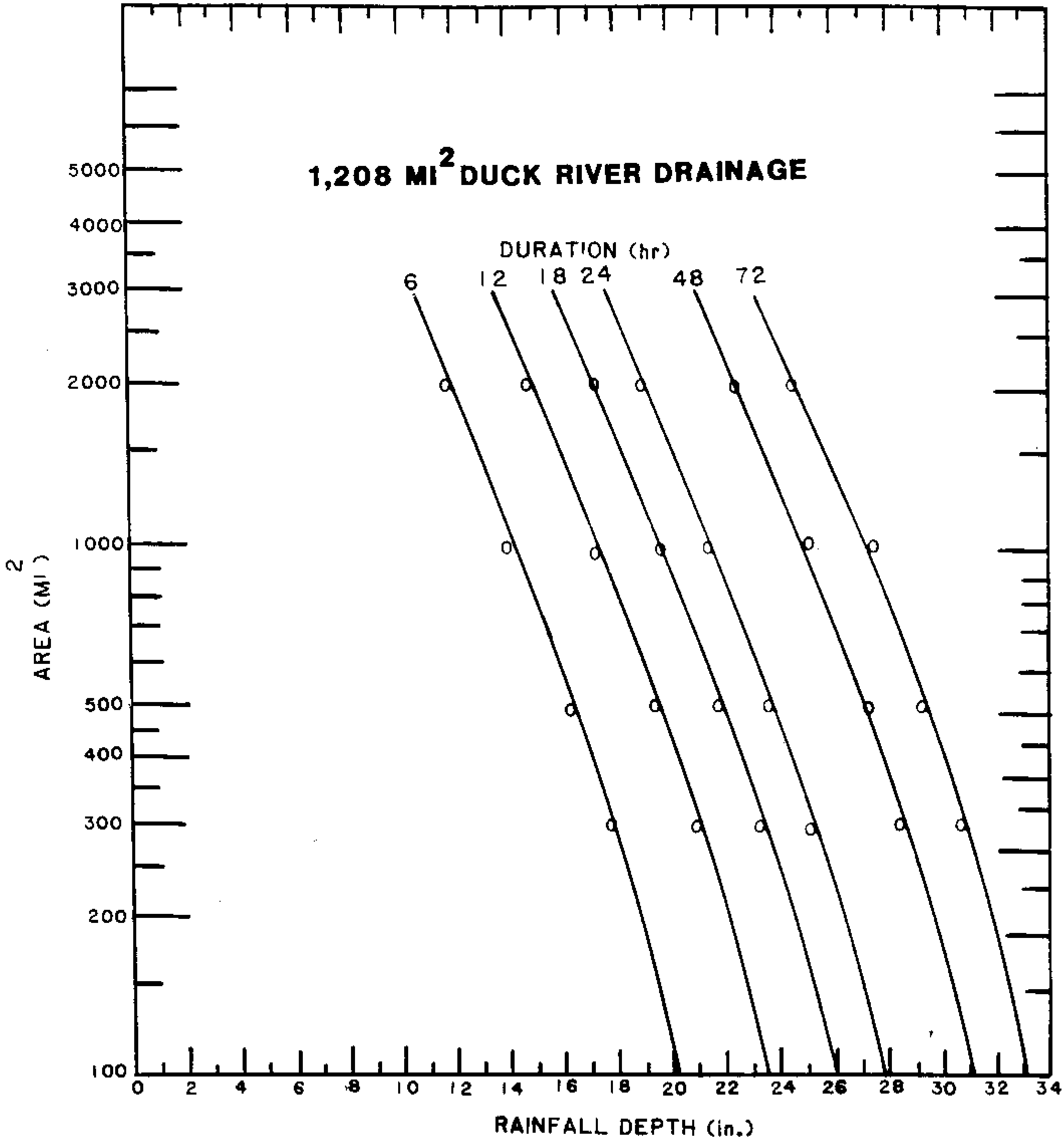


Figure 87.--DAD data valid for Duck River drainage; center 35°34'N, 86°32'W.

<u>Step</u> (areal distribution sect. 5.4.1)

3-1. Place the idealized isohyetal pattern from figure 72 over the basin to put the maximum volume into the drainage. This is shown in figure 88. Our judgment of best fit enclosed the "G" isohyet within the basin, while the "K" isohyet encloses the basin.

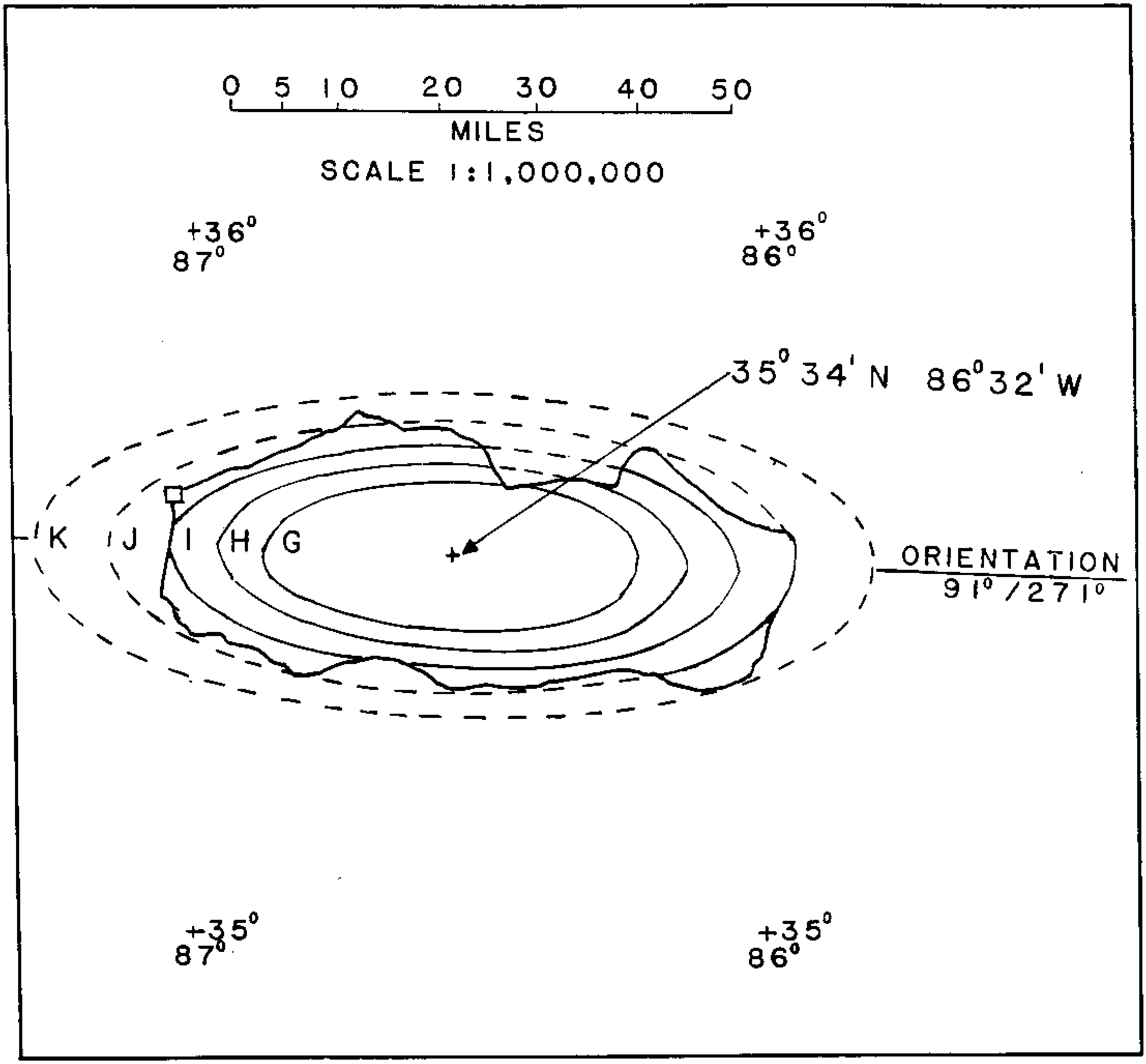


Figure 88.--Elliptical pattern centered over the Duck River drainage.

3-2. From step 3 for PMP in this example, read off a set of depth-duration values for 3 to 4 standard area sizes both larger and smaller than 1,208 mi^2 (Duck River drainage area) as follows;

Standard Area (mi^2)	Duration (hr) 6	12	18	24	48	72
300	17.7	21.0	23.4	26.2	28.5	30.8
450	16.5	19.9	22.2	24.0	27.3	29.6
700	15.2	18.5	20.8	22.6	26.0	28.2
1000	14.0	17.2	19.5	21.4	24.9	27.2
1500	12.7	15.8	18.1	20.1	23.4	25.6
2150	11.5	14.5	16.8	18.7	22.0	24.2
3000	10.3	13.2	15.5	17.5	20.9	22.9

Incremental differences for each of the first three 6-hr periods are shown below.

Standard Area (mi^2)	6-hr Periods 1	2	3
300	17.7	3.3	2.4
450	16.5	3.4	2.3
700	15.2	3.3	2.3
1000	14.0	3.2	2.3
1500	12.7	3.1	2.3
2150	11.5	3.0	2.3
3000	10.3	2.9	2.3

In figure 89, the data from the above table are smoothed resulting in the following incremental data (read to hundredths of an inch).

Standard Area (mi^2)	6-hr Periods 1	2	3
300	17.80	3.33	2.40
450	16.52	3.29	2.38
700	15.10	3.23	2.33
1000	13.98	3.19	2.31
1500	12.70	3.15	2.28
2150	11.35	3.10	2.25
3000	10.50	2.92	2.20

3-4. The orientation of the pattern placed as in figure 87 of step 3-1 is 091°/271°. The 91°, measured from north, lies outside the specified range (135° to 315°), and we accordingly added 180° to get the orientation of 271° for this example.

3-5. From figure 73, the preferred orientation for this location is 237°. The absolute difference between this step and step 3-4, or $|237° - 271°| = 34°$, is less than the 40° threshold needed before reductions apply. Therefore, no adjustment for orientation is necessary in this example.

3-6. Since the difference in step 3-5 is less than 40°, the orientation adjustment is equal to 1.0.

3-7. Determine the maximum volume of precipitation for the PMP patterns corresponding to the 7 area sizes listed in step 3-3. Following the procedure outlined in steps 7a through 7j, this fills in table 16. (It should be noted, however, that computing some additional non-standard PMP pattern sizes such as 1,200 and 1,800 mi^2 might be in order. For simplicity we will not make these supplemental computations here.)

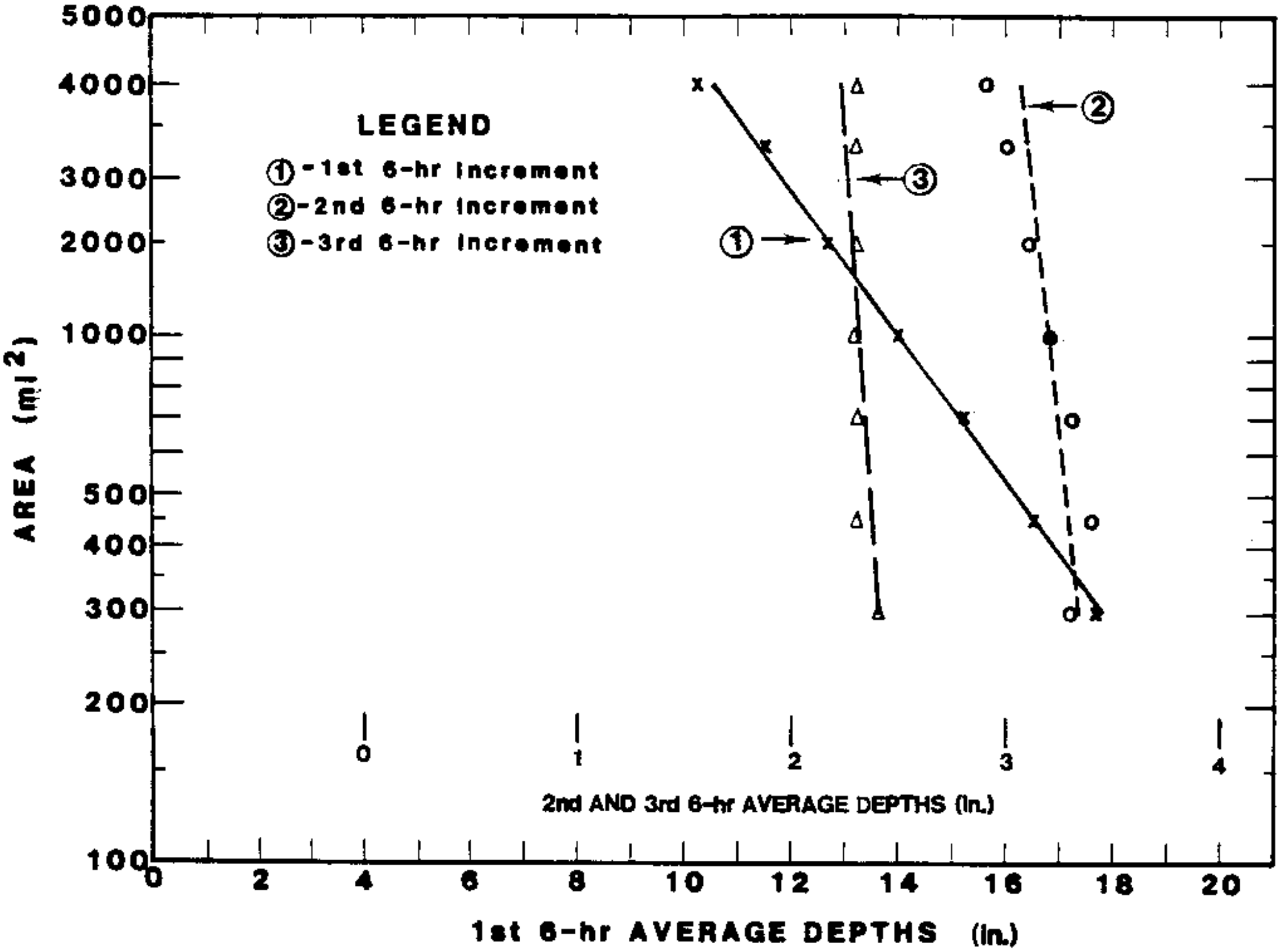


Figure 89.--Smoothing curves for the first three 6-hr incremental depth-area data, Duck River basin.

For each pattern area size, the volumetric precipitation is added for the 3 largest 6-hr amounts and plotted in figure 90. The results show a maximum volume occurring at an area size of 1,500 mi^2. This is the PMP storm-area size. (If supplementary isohyets had been tested, it is possible the maximum volume might occur at a slightly larger or smaller area size.)

3-8a. Determine the basin-averaged PMP over the basin. To do this read off the storm-averaged 6-hr values for a smoothed depth-duration curve for a 1,500-mi^2 area based on the data from figure 87, and for the basin as located in figure 88. This gives, using figure 91,

Duration (hr)	6	12	18	24	30	36	42	48	54	60	66	72
PMP (in.)	12.7	15.8	18.1	20.1	21.3	22.3	23.2	23.8	24.3	24.8	25.2	25.6

Table 16.—Completed computation sheets for 1st, 2nd, and 3rd 6-hr increments for Duck River basin

Increment: 1

Drainage: Duck River above Columbia, Tenn. Area: 1,208 mi^2 Date:

I		II	III	IV	V	VI	I		II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 17.80	Avg. depth	ΔA	ΔV	Area size	Iso.	Nomo.	Amt. 13.98	Avg. depth	ΔA	ΔV
300/1*	A	126.5	22.52	22.52	10	225.2	1000/1	A	149	20.83	20.83	10	208.3
	B	118	21.00	21.76	15	326.4		B	140	19.57	20.20	15	303.0
	C	110.5	19.67	20.34	25	508.4		C	131	18.31	18.94	25	473.6
	D	103	18.33	19.00	50	950.1		D	122	17.06	17.68	50	884.2
	E	96	17.09	17.71	75	1328.3		E	113	15.80	16.43	75	1232.0
	F	88	15.66	16.38	125	2047.0		F	104	14.54	15.17	125	1896.0
	G	66	11.75	13.71	150	2055.9		G	97	13.56	14.05	150	2107.5
	H	52	9.26	10.50	224	2351.1		H	89	12.44	13.00	224	2910.6
	I	42	7.48	8.37	285	2383.6		I	82	11.46	11.95	285	3405.6
	J	32	5.70	6.59	232	1528.0		J	59.5	8.32	9.89	232	2294.8
(.85x)#	K	25	4.45	5.51	81	448.5	(.85x)	K	43.5	6.08	7.98	81	649.9
						Sum = 14152.5							Sum = 16365.5

Area size			Amt. 16.52				Area size			Amt. 12.70			
450/1	A	132.5	21.89	21.89	10	218.9	1500/1	A	162	20.57	20.57	10	205.7
	B	124	20.48	21.19	15	317.8		B	152	19.30	19.94	15	299.1
	C	116	19.16	19.82	25	495.6		C	142	18.03	18.67	25	466.7
	D	108	17.84	18.50	50	925.1		D	132	16.76	17.40	50	869.9
	E	101	16.69	17.26	75	1294.8		E	122	15.49	16.13	75	1209.7
	F	93	15.36	16.02	125	2003.1		F	112.5	14.29	14.89	125	1861.3
	G	86	14.21	14.79	150	2217.8		G	104.5	13.27	13.78	150	2066.9
	H	63	10.41	12.31	224	2755.3		H	96	12.19	12.73	224	2850.3
	I	50	8.26	9.33	285	2659.4		I	88.5	11.24	11.72	285	3338.1
	J	38.5	6.36	7.31	232	1696.0		J	80	10.16	10.70	232	2482.4
(.85x)#	K	30.0	4.96	6.15	81	500.6	(.85x)	K	56	7.11	9.70	81	789.9
						Sum = 15084.3							Sum = 16440.0

Area size			Amt. 15.10				Area size			Amt. 11.35			
700/1	A	140.5	21.22	21.22	10	212.2	2150/1	A	176	19.98	19.98	10	199.8
	B	132	19.93	20.57	15	308.6		B	165	18.73	19.35	15	290.3
	C	124	18.72	19.33	25	483.2		C	153.4	17.41	18.07	25	451.7
	D	115	17.37	18.04	50	902.2		D	142.5	16.17	16.79	50	839.5
	E	107.5	16.23	16.80	75	1259.9		E	131	14.87	15.52	75	1164.1
	F	98	14.80	15.52	125	1939.4		F	122	13.85	14.36	125	1794.7
	G	91.5	13.82	14.31	150	2146.1		G	113	12.83	13.34	150	2000.4
	H	84	12.86	13.25	224	2966.3		H	103	11.69	12.26	224	2744.2
	I	64	9.66	11.17	285	3183.7		I	95	10.78	11.24	285	3201.5
	J	48	7.25	8.46	232	1961.9		J	86	9.76	10.27	232	2383.2
(.85x)	K	36	5.44	6.98	81	567.9	(.85x)	K	77	9.74	9.61	81	782.2
						Sum = 15431.4							Sum = 15851.6

*300/1 = Computation for the 300-mi^2 PMP pattern, 1st 6-hr increment.
#weights applied for partial areas

Table 16.--Completed computation sheets for 1st, 2nd, and 3rd 6-hr increments for Duck River basin (continued).

Increment: 1, 2

Drainage: Duck River above Columbia, Tenn. Area: 1,208 mi^2 Date:

I		II	III	IV	V	VI	I		II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 10.50	Avg. depth	ΔA	ΔV	Area size	Iso.	Nomo.	Amt. 3.23	Avg. depth	ΔA	ΔV
3000/1	A	191	20.06	20.06	10	200.6	800/2	A	114.5	3.70	3.70	10	37.0
	B	178.5	18.74	19.40	15	291.0		B	110.5	3.57	3.63	15	54.5
	C	166	17.43	18.09	25	452.2		C	107	3.46	3.51	25	87.8
	D	154	16.17	16.80	50	840.0		D	104	3.36	3.41	50	170.4
	E	142	14.91	15.54	75	1165.5		E	101	3.26	3.31	75	248.3
	F	132	13.86	14.39	125	1798.1		F	99	3.20	3.23	125	403.7
	G	122	12.81	13.34	150	2000.2		G	97.1	3.14	3.17	150	475.1
	H	112	11.76	12.29	224	2750.2		H	95	3.07	3.10	224	694.7
	I	102.5	10.76	11.26	285	3208.6		I	78	2.52	2.79	285	796.1
	J	92	9.66	10.21	232	2369.1		J	66	2.13	2.33	232	539.6
(.85x)	K	83	8.72	9.52	81	774.9	(.85x)	K	54	1.74	2.07	81	168.8
						Sum = 15850.4							Sum = 3676.0

Area size	Iso.	Nomo.	Amt. 3.33	Avg. depth	ΔA	ΔV	Area size	Iso.	Nomo.	Amt. 3.19	Avg. depth	ΔA	ΔV
300/2	A	112	3.73	3.73	10	37.3	1000/2	A	116	3.70	3.70	10	37.0
	B	107	3.56	3.65	15	54.7		B	112	3.57	3.64	15	54.5
	C	103.5	3.45	3.50	25	87.6		C	108.5	3.46	3.52	25	87.9
	D	100	3.33	3.39	50	169.4		D	105	3.35	3.41	50	170.3
	E	98	3.26	3.30	75	247.2		E	103	3.29	3.32	75	248.8
	F	95	3.16	3.21	125	401.7		F	101	3.22	3.25	125	406.7
	G	80	2.66	2.91	150	437.1		G	99	3.16	3.19	150	478.0
	H	67.5	2.25	2.46	224	549.8		H	97	3.09	3.13	224	699.9
	I	57	1.90	2.07	285	590.6		I	95	3.03	3.06	285	872.5
	J	47	1.57	1.73	232	401.7		J	76	2.42	2.73	232	632.8
(.85x)	K	38	1.27	1.52	81	123.8	(.85x)	K	63	2.01	2.36	81	192.3
						Sum = 3100.9							Sum = 3880.7

Area size	Iso.	Nomo.	Amt. 3.29	Avg. depth	ΔA	ΔV	Area size	Iso.	Nomo.	Amt. 3.15	Avg. depth	ΔA	ΔV
450/2	A	113	3.72	3.72	10	37.2	1500/2	A	117	3.69	3.69	10	36.9
	B	109	3.59	3.65	15	54.8		B	113	3.56	3.62	15	54.3
	C	105	3.45	3.52	25	88.0		C	110	3.47	3.51	25	87.8
	D	102	3.36	3.41	50	170.3		D	107	3.37	3.42	50	170.9
	E	99.5	3.27	3.31	75	248.6		E	105	3.31	3.34	75	250.4
	F	97	3.19	3.23	125	404.1		F	103	3.24	3.28	125	409.5
	G	95	3.13	3.16	150	473.8		G	101	3.18	3.21	150	481.9
	H	77.5	2.55	2.84	224	635.3		H	99	3.12	3.15	224	705.2
	I	66	2.17	2.36	285	672.6		I	97	3.06	3.09	285	879.5
	J	55	1.01	1.99	232	461.8		J	95	2.99	3.02	232	701.6
(.85x)	K	45	1.48	1.76	81	143.3	(.85x)	K	75.5	2.38	2.90	81	236.1
						Sum = 3389.8							Sum = 4014.2

Table 16.--Completed computation sheets for 1st, 2nd, and 3rd 6-hr increments for Duck River basin (continued).

Drainage: Duck River above Columbia, Tenn. Area: 1,208 mi^2 Increment: 2, 3 Date:

	I	II	III	IV	V	VI		I	II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 3.10	Avg. depth	ΔA	ΔV	Area size	Iso.	Nomo.	Amt. 2.38	Avg. depth	ΔA	ΔV
2150/2	A	118.5	3.67	3.67	10	36.7	450/3	A	103.8	2.47	2.47	10	24.7
	B	114.5	3.55	3.61	15	54.2		B	102.4	2.44	2.45	15	36.8
	C	111.5	3.46	3.50	25	87.6		C	101.2	2.41	2.42	25	60.6
	D	108.5	3.36	3.41	50	170.5		D	100.3	2.39	2.40	50	119.9
	E	106.5	3.30	3.33	75	249.9		E	99.8	2.38	2.38	75	178.6
	F	104.5	3.24	3.27	125	408.8		F	99.5	2.37	2.37	125	296.5
	G	102.1	3.17	3.20	150	480.3		G	99.2	2.36	2.36	150	354.7
	H	100	3.10	3.13	224	701.3		H	84	2.00	2.18	224	488.1
	I	99	3.07	3.08	285	878.8		I	71.2	1.69	1.85	285	526.2
	J	97	3.01	3.04	232	704.8		J	60	1.43	1.56	232	362.2
(.85x)	K	96.5	2.99	3.00	81	244.6	(.85x)	K	50	1.19	1.39	81	113.3
					Sum =	4017.5						Sum =	2561.6

Area size	Iso.	Nomo.	Amt. 2.92	Avg. depth	ΔA	ΔV	Area size	Iso.	Nomo.	Amt. 2.33	Avg. depth	ΔA	ΔV
3000/2	A	119.5	3.49	3.49	10	34.9	700/3	A	104.2	2.43	2.43	10	24.3
	B	116	3.39	3.44	15	51.6		B	102.9	2.40	2.41	15	36.2
	C	112.5	3.29	3.34	25	83.4		C	101.7	2.37	2.38	25	59.6
	D	110	3.21	3.25	50	162.4		D	100.9	2.35	2.36	50	118.0
	E	108	3.15	3.18	75	238.7		E	100.2	2.33	2.34	75	175.7
	F	106	3.10	3.12	125	390.5		F	99.9	2.33	2.33	125	291.4
	G	104	3.04	3.07	150	459.9		G	99.6	2.32	2.32	150	348.6
	H	101.9	2.98	3.01	224	673.0		H	99.2	2.31	2.32	224	518.5
	I	100.5	2.93	2.96	285	841.9		I	85	1.98	2.15	285	611.4
	J	99	2.89	2.91	232	675.8		J	70.5	1.64	1.81	232	420.3
(.85x)	K	97	2.83	2.88	81	234.6	(.85x)	K	58.5	1.36	1.60	81	130.3
					Sum =	3846.7						Sum =	2734.3

Area size	Iso.	Nomo.	Amt. 2.40	Avg. depth	ΔA	ΔV	Area size	Iso.	Nomo.	Amt. 2.31	Avg. depth	ΔA	ΔV
300/3	A	103.4	2.48	2.48	10	24.8	1000/3	A	104.6	2.42	2.42	10	24.2
	B	101.9	2.45	2.46	15	36.9		B	103.3	2.39	2.40	15	36.0
	C	100.7	2.42	2.43	25	60.8		C	102.2	2.36	2.37	25	59.3
	D	99.8	2.40	2.41	50	120.3		D	101.3	2.34	2.35	50	117.5
	E	99.3	2.38	2.39	75	179.2		E	100.6	2.32	2.33	75	174.9
	F	99	2.38	2.38	125	297.4		F	100.3	2.32	2.32	125	290.1
	G	86	2.06	2.22	150	333.0		G	99.9	2.31	2.31	150	346.8
	H	72	1.73	1.90	224	424.5		H	99.6	2.30	2.30	224	515.8
	I	62	1.49	1.61	285	458.1		I	99.3	2.29	2.30	285	654.5
	J	53	1.27	1.38	232	320.2		J	82.5	1.91	2.10	232	487.2
(.85x)	K	43	1.03	1.24	81	100.6	(.85x)	K	67.0	1.55	1.85	81	150.8
					Sum =	2355.8						Sum =	2857.1

Table 16.--Completed computation sheets for 1st, 2nd, and 3rd 6-hr increments for Duck River basin (continued).

Drainage: Duck River above Columbia, Tenn. Area: 1,208 mi^2 Increment: 1, 2 Date:

I		II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 10.50	Avg. depth	ΔA	ΔV
3000/1	A	191	20.06	20.06	10	200.6
	B	178.5	18.74	19.40	15	291.0
	C	166	17.43	18.09	25	452.2
	D	154	16.17	16.80	50	840.0
	E	142	14.91	15.54	75	1165.5
	F	132	13.86	14.39	125	1798.1
	G	122	12.81	13.34	150	2000.2
	H	112	11.76	12.29	224	2750.2
	I	102.5	10.76	11.26	285	3208.6
	J	92	9.66	10.21	232	2369.1
(.85x)	K	83	8.72	9.52	81	774.9
						Sum = 15850.4

I		II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 3.23	Avg. depth	ΔA	ΔV
800/2	A	114.5	3.70	3.70	10	37.0
	B	110.5	3.57	3.63	15	54.5
	C	107	3.46	3.51	25	87.8
	D	104	3.36	3.41	50	170.4
	E	101	3.26	3.31	75	248.3
	F	99	3.20	3.23	125	403.7
	G	97.1	3.14	3.17	150	475.1
	H	95	3.07	3.10	224	694.7
	I	78	2.52	2.79	285	796.1
	J	66	2.13	2.33	232	539.6
(.85x)	K	54	1.74	2.07	81	168.8
						Sum = 3676.0

Area size			Amt. 3.33			
300/2	A	112	3.73	3.73	10	37.3
	B	107	3.56	3.65	15	54.7
	C	103.5	3.45	3.50	25	87.6
	D	100	3.33	3.39	50	169.4
	E	98	3.26	3.30	75	247.2
	F	95	3.16	3.21	125	401.7
	G	80	2.66	2.91	150	437.1
	H	67.5	2.25	2.46	224	549.8
	I	57	1.90	2.07	285	590.6
	J	47	1.57	1.73	232	401.7
(.85x)	K	38	1.27	1.52	81	123.8
						Sum = 3100.9

Area size			Amt. 3.19			
1000/2	A	116	3.70	3.70	10	37.0
	B	112	3.57	3.64	15	54.5
	C	108.5	3.46	3.52	25	87.9
	D	105	3.35	3.41	50	170.3
	E	103	3.29	3.32	75	248.8
	F	101	3.22	3.25	125	406.7
	G	99	3.16	3.19	150	478.0
	H	97	3.09	3.13	224	699.9
	I	95	3.03	3.06	285	872.5
	J	76	2.42	2.73	232	632.8
(.85x)	K	63	2.01	2.36	81	192.3
						Sum = 3880.7

Area size			Amt. 3.29			
450/2	A	113	3.72	3.72	10	37.2
	B	109	3.59	3.65	15	54.8
	C	105	3.45	3.52	25	88.0
	D	102	3.36	3.41	50	170.3
	E	99.5	3.27	3.31	75	248.6
	F	97	3.19	3.23	125	404.1
	G	95	3.13	3.16	150	473.8
	H	77.5	2.55	2.84	224	635.3
	I	66	2.17	2.36	285	672.6
	J	55	1.01	1.99	232	461.8
(.85x)	K	45	1.48	1.76	81	143.3
						Sum = 3389.8

Area size			Amt. 3.15			
1500/2	A	117	3.69	3.69	10	36.9
	B	113	3.56	3.62	15	54.3
	C	110	3.47	3.51	25	87.8
	D	107	3.37	3.42	50	170.9
	E	105	3.31	3.34	75	250.4
	F	103	3.24	3.28	125	409.5
	G	101	3.18	3.21	150	481.9
	H	99	3.12	3.15	224	705.2
	I	97	3.06	3.09	285	879.5
	J	95	2.99	3.02	232	701.6
(.85x)	K	75.5	2.38	2.90	81	236.1
						Sum = 4014.2

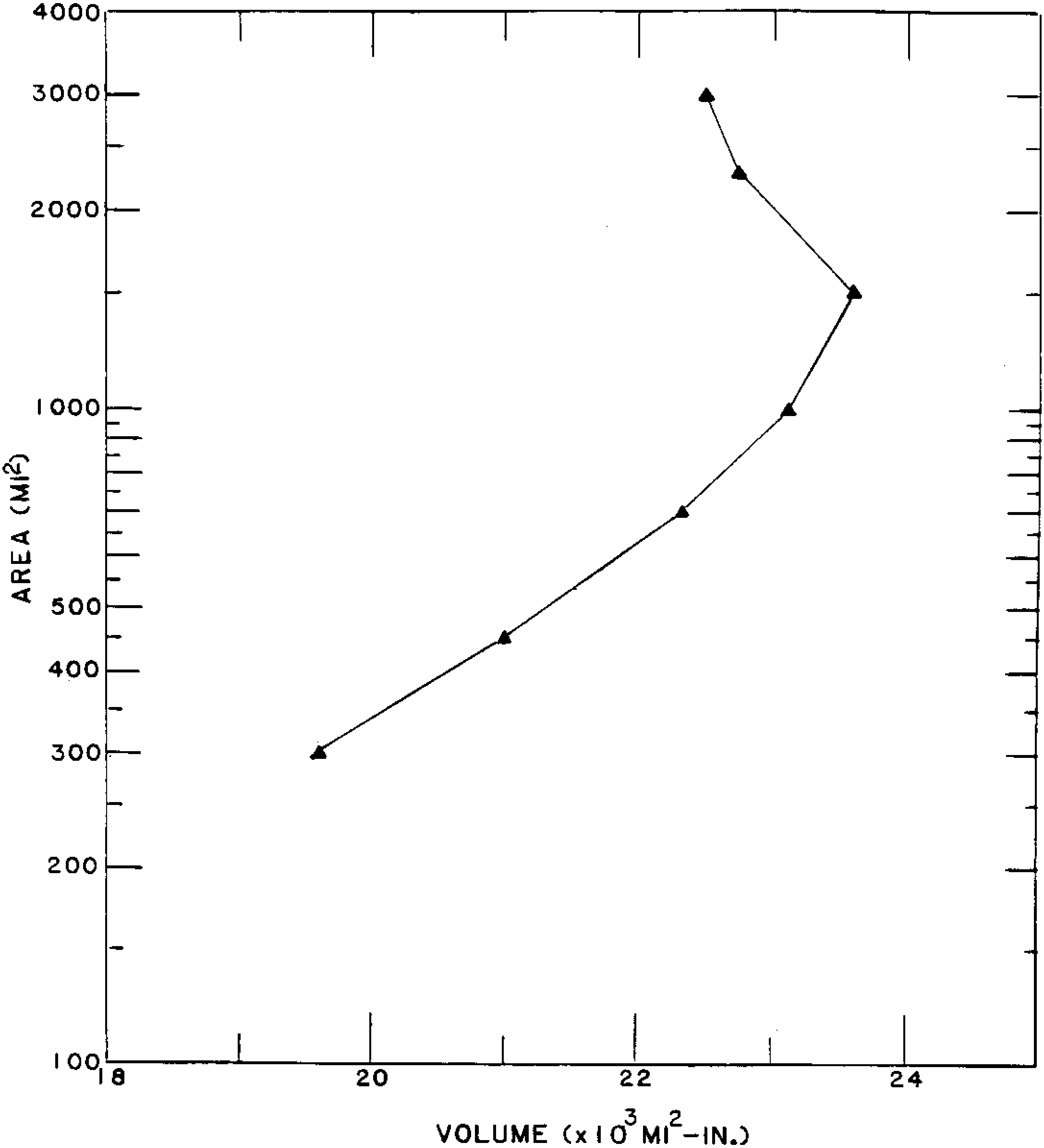


Figure 90.--Volume vs. area curve for the first three 6-hr increments for Duck River basin.

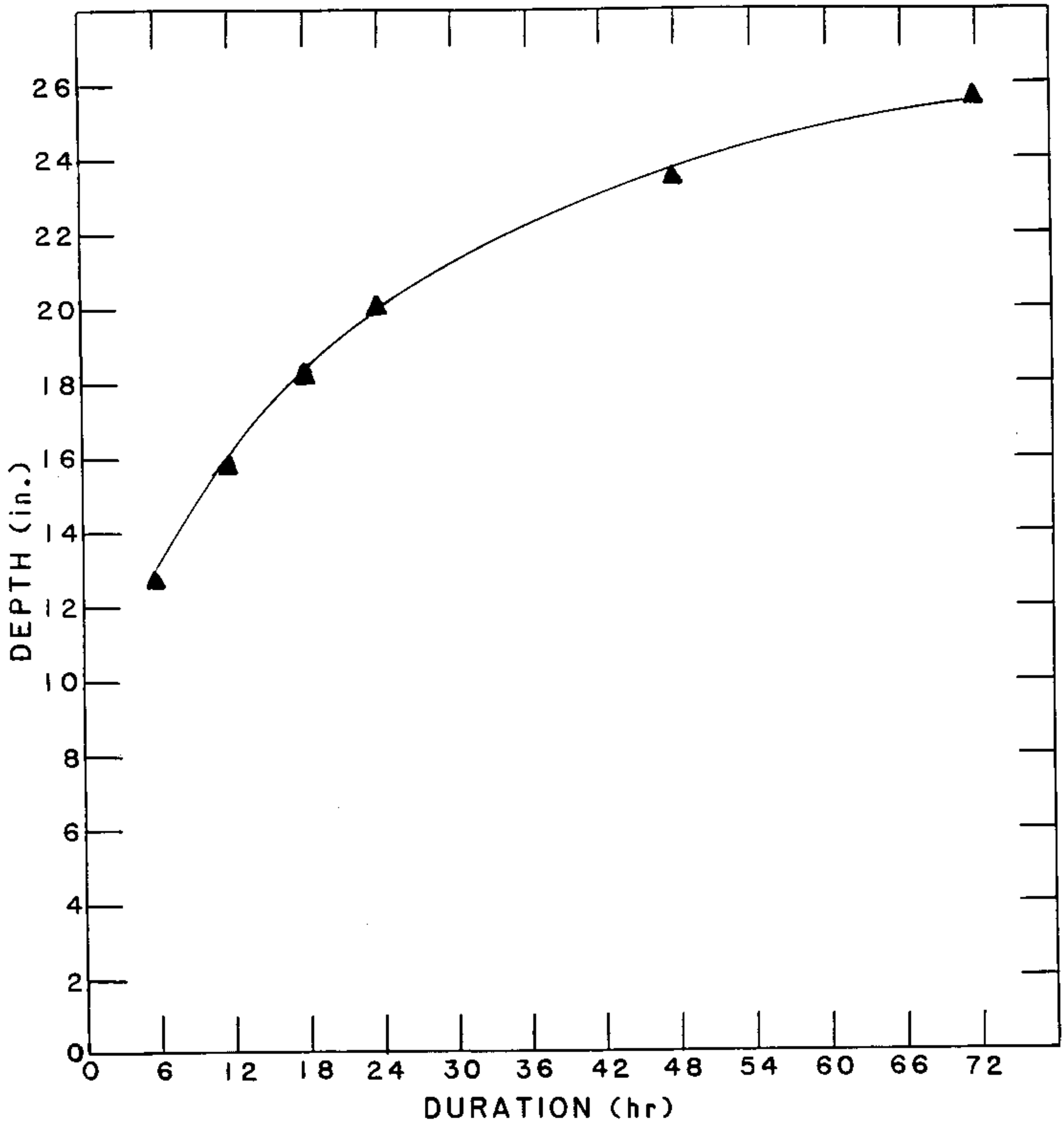


Figure 91.—Depth-duration curve for 1,500 mi^2 for Duck River basin.

b. Subtract each 6-hr value in step 3-8a from the next lower durational value to get incremental amounts.

6-hr Increm.	1	2	3	4	5	6	7	8	9	10	11	12
PMP(in.)	12.7	3.1	2.3	2.0	1.2	1.0	0.9	0.6	0.5	0.5	0.4	0.4

le 17. Isohyet values (in.) of PMP for Duck River example

Isohyet	6-hr Periods 1	2	3	4	5	6	7	8	9	10	11	12
A	20.57	3.69	2.39	2.00	1.20	1.00	0.90	0.60	0.50	0.50	0.40	0.40
B	19.30	3.56	2.37	2.00	1.20	1.00	0.90	0.60	0.50	0.50	0.40	0.40
C	18.03	3.47	2.34	2.00	1.20	1.00	0.90	0.60	0.50	0.50	0.40	0.40
D	16.76	3.37	2.32	2.00	1.20	1.00	0.90	0.60	0.50	0.50	0.40	0.40
E	15.49	3.31	2.30	2.00	1.20	1.00	0.90	0.60	0.50	0.50	0.40	0.40
F	14.29	3.24	2.30	2.00	1.20	1.00	0.90	0.60	0.50	0.50	0.40	0.40
G	13.27	3.18	2.29	2.00	1.20	1.00	0.90	0.60	0.50	0.50	0.40	0.40
H	12.19	3.12	2.28	2.00	1.20	1.00	0.90	0.60	0.50	0.50	0.40	0.40
I	11.24	3.06	2.27	2.00	1.20	1.00	0.90	0.60	0.50	0.50	0.40	0.40
J	10.16	2.99	2.27	2.00	1.20	1.00	0.90	0.60	0.50	0.50	0.40	0.40
K	7.11	2.38	1.85	1.63	0.97	0.81	0.73	0.49	0.41	0.41	0.32	0.32

c. Isohyet values (labels) are obtained by multiplying each incremental depth times the respective percentages from tables 12, 13, 14 and 15. The results are shown in table 17. Concurrent basins are not discussed in this example.

d. The basin-averaged incremental 6-hr PMP for all 12 6-hr increments are obtained from the data in step 3-8c. Planimeter the isohyet pattern in figure 88 with the percentages given for the 1st 6-hr period, and determine the incremental volume of precipitation in the drainage. As shown in table 16, this amounts to 16,440 mi^2 in. Dividing this by the basin area gives an average depth for the 1st 6-hr period. Note that total area for this drainage in table 16 is measured as 1,272 mi^2, not the 1,208 mi^2 given initially. The larger number represents the error obtained in the planimetering step and is used here to get the average depth of 12.9 in. Had the incremental depths in table 16 been adjusted initially, somewhat lower volumes would have been obtained. Either approach may be used to get the average depth. The remaining 6-hr incremental depths, are then:

6-hr increm.	1	2	3	4	5	6	7	8	9	10	11	12
PMP (in.)	12.9	3.2	2.3	2.0	1.2	1.0	0.9	0.6	0.5	0.5	0.4	0.4

If these incremental depths are summed, we get 25.9 in. which can be compared with the 72-hr storm-area averaged nonorographic PMP for 1,208-mi^2 (from fig. 87) of 26.8 in. The reduction of roughly 3 percent is caused by factors related to the shape of the basin.

e. Determine the TSF from section 5.4.3.1

Step

e.1. From figure 67, the entire Duck River basin is located in the smooth terrain zone. Therefore, there is no terrain adjustment factor for this example and the answers obtained in step 3-8d are the appropriate basin-averaged PMP for the Duck River basin.

f. Determine the TVA precipitation for the basin.

Since the basin is located in the entirely "smooth" terrain, the PMP values in step 8a are multiplied by the factor 0.53, which is the ratio of "smooth" TVA precipitation to "smooth" PMP precipitation-valid from 6 to 72 hr. Therefore, the resulting basin-averaged TVA precipitation for the Duck River basin is:

Dur. (hr.)	6	12	18	24	30	36	42	48	54	60	66	72
TVA prec. (in.)	6.8	8.5	9.7	10.8	11.4	12.0	12.5	12.8	13.0	13.2	13.4	13.6

By multiplying the isohyet values in table 17 by 0.53, one obtains the isohyetal depths representing the areal distribution of the TVA precipitation for the Duck River basin. This is shown in the following table:

Isohyet values (in.) for TVA precipitation in Duck River example

	6-hr periods											
Isohyet	1	2	3	4	5	6	7	8	9	10	11	12
A	10.90	1.96	1.27	1.06	0.64	0.53	0.48	0.32	0.27	0.27	0.21	0.21
B	10.23	1.89	1.26	1.06	0.64	0.53	0.48	0.32	0.27	0.27	0.21	0.21
C	9.56	1.84	1.24	1.06	0.64	0.53	0.48	0.32	0.27	0.27	0.21	0.21
D	8.88	1.79	1.23	1.06	0.64	0.53	0.48	0.32	0.27	0.27	0.21	0.21
E	8.21	1.75	1.22	1.06	0.64	0.53	0.48	0.32	0.27	0.27	0.21	0.21
F	7.57	1.72	1.22	1.06	0.64	0.53	0.48	0.32	0.27	0.27	0.21	0.21
G	7.03	1.69	1.21	1.06	0.64	0.53	0.48	0.32	0.27	0.27	0.21	0.21
H	6.46	1.65	1.21	1.06	0.64	0.53	0.48	0.32	0.27	0.27	0.21	0.21
I	5.96	1.62	1.20	1.06	0.64	0.53	0.48	0.32	0.27	0.27	0.21	0.21
J	5.38	1.58	1.20	1.06	0.64	0.53	0.48	0.32	0.27	0.27	0.21	0.21
K	3.77	1.26	0.99	0.86	0.51	0.43	0.39	0.26	0.22	0.22	0.17	0.17

5.5.5. Areal Distribution of Large-Basin PMP and Concurrent Basin Precipitation in the Mountainous East

The basin chosen for this example is the Little Tennessee River drainage above Franklin, TN considered in section 5.5.3 and shown as subbasin 8 along with concurrent basins in figure 92. This portion of the example continues the procedure by areally distributing the basin-averaged total PMP, and considers as well, the precipitation amounts that occur on selected concurrent basins (A, B, C, and D in fig. 92). The example makes use of procedures in sections 5.4.1, 5.4.2, and 5.4.4.2.

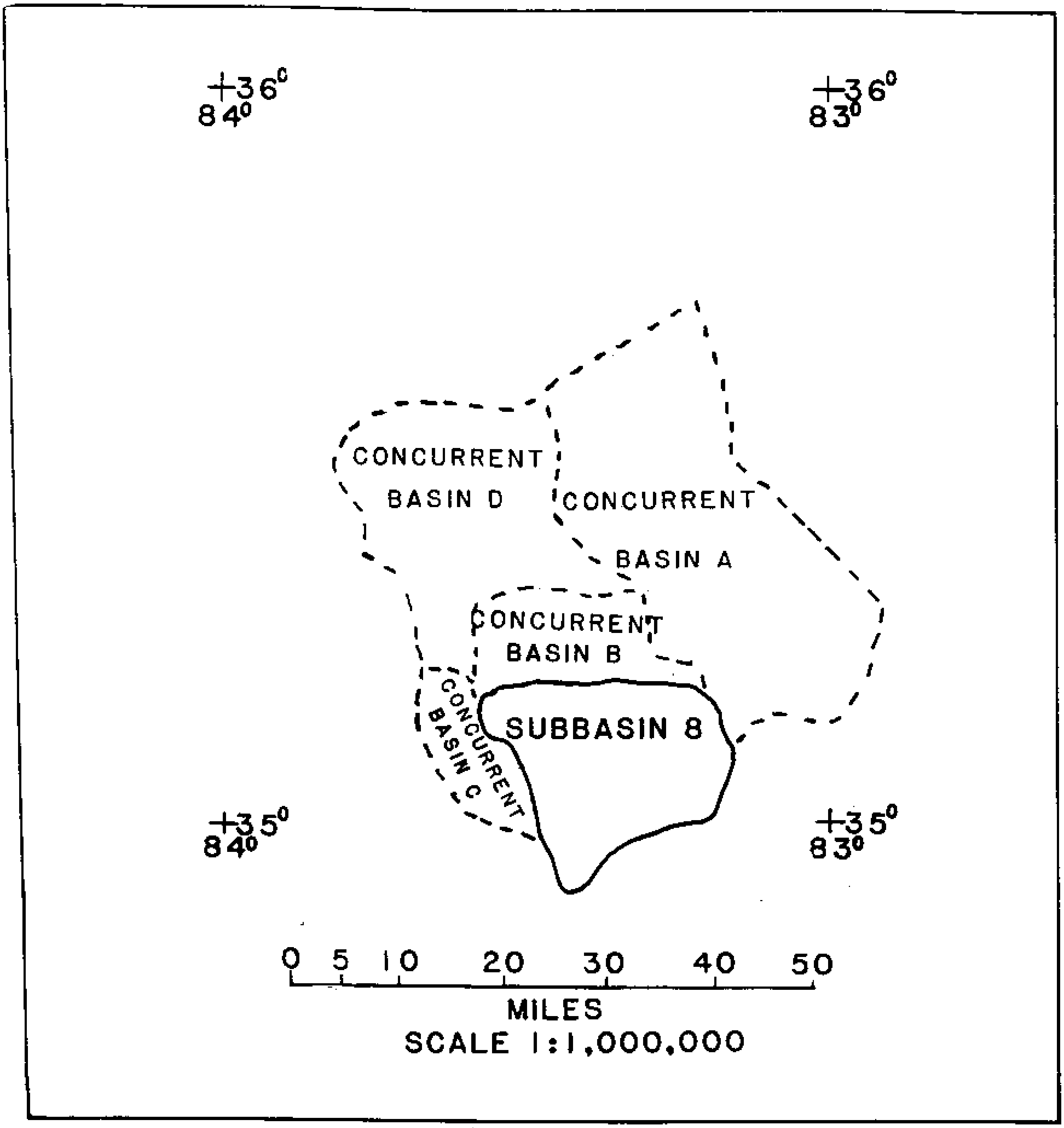


Figure 92.--Concurrent basins relative to Little Tennessee River basin.

Step (for areal distribution sect. 5.4.2)

1. Determine basin-centered total PMP pattern and isohyetal values from section 5.4 and 5.4.1 steps 1 to 8c.

   1-1. Place the idealized isohyetal pattern from figure 67 on the primary drainage with an orientation that will give maximum volume in the drainage (fig. 93).

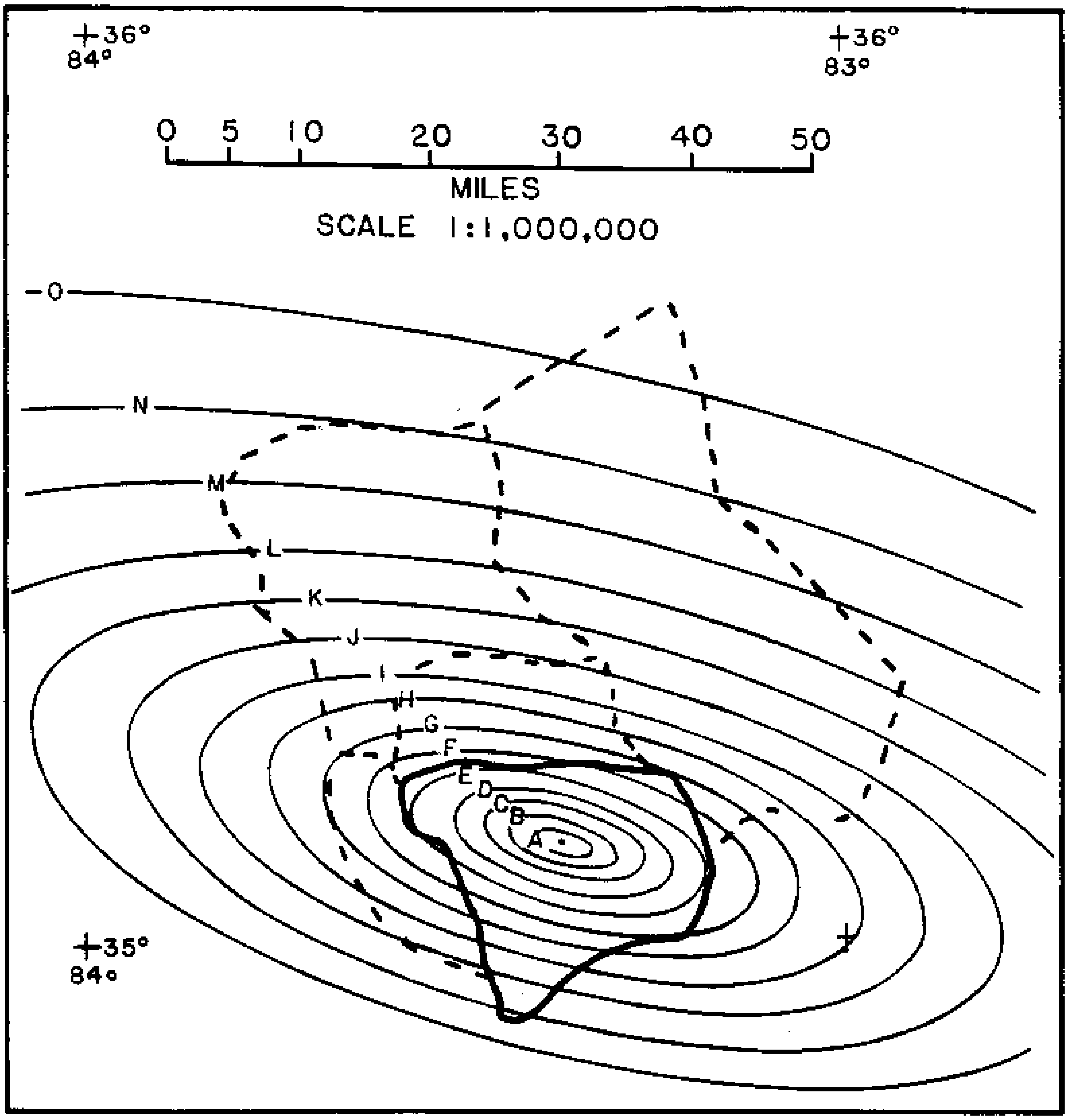


Figure 93.--Elliptical pattern centered over the Little Tennessee River drainage.

Table 18.--Isohyet values (in.) for total PMP for the Little Tennessee River basin.

Isohyet	1	2	3	4	5	6	7	8	9	10	11	12
A	29.42	4.86	2.44	2.20	1.80	1.50	1.00	1.00	0.90	0.70	0.60	0.60
B	27.53	4.69	2.41	2.20	1.80	1.50	1.00	1.00	0.90	0.70	0.60	0.60
C	25.75	4.52	2.38	2.20	1.80	1.50	1.00	1.00	0.90	0.70	0.60	0.60
D	23.98	4.39	2.36	2.20	1.80	1.50	1.00	1.00	0.90	0.70	0.60	0.60
E	22.42	4.28	2.35	2.20	1.80	1.50	1.00	1.00	0.90	0.70	0.60	0.60
F	20.65	4.17	2.34	2.20	1.80	1.50	1.00	1.00	0.90	0.70	0.60	0.60
G	19.09	4.09	2.33	2.20	1.80	1.50	1.00	1.00	0.90	0.70	0.60	0.60
H	13.99	3.33	1.97	1.85	1.51	1.26	0.84	0.84	0.76	0.59	0.50	0.50
I	11.10	2.84	1.67	1.56	1.28	1.07	0.71	0.71	0.64	0.50	0.43	0.43
J	8.55	2.37	1.41	1.32	1.08	0.90	0.60	0.60	0.54	0.42	0.36	0.36
K	6.66	1.94	1.18	1.10	0.90	0.75	0.50	0.50	0.45	0.35	0.30	0.30
L	5.11	1.57	0.93	0.87	0.71	0.59	0.40	0.40	0.36	0.28	0.24	0.24
M	3.33	1.10	0.71	0.66	0.54	0.45	0.30	0.30	0.27	0.21	0.18	0.18
N	1.78	0.60	0.45	0.42	0.34	0.29	0.19	0.19	0.17	0.13	0.11	0.11
O	0.67	0.19	0.16	0.15	0.13	0.11	0.07	0.07	0.06	0.05	0.04	0.04

1-2 to 1-8. Details of the computation to find the area of the PMP storm that gives maximum volume are not given here, as they are lengthy and follow closely those already exhibited in section 5.4.1. The TAF for subbasin 8 was computed to be 1.35 (sect. 5.5.3).

From this procedure, it was determined that a PMP storm area size of 450 mi^2 produced the maximum volume in the 295-mi^2 Little Tennessee River basin. As a result, isohyets A to G represent the PMP storm in figure 92 and isohyets H to O are residual precipitation. Values for total PMP for each 6-hr increment are given in table 18.

2. Adjust the basin-centered pattern toward the location of maximum 2-yr 24-hr amount in the basin. From figure 59, for the Little Tennessee River basin, this would be toward the southwest; however, since the basin is so small and because of the condition to limit displacement to 10 mi inside the basin boundary, no displacement is given for this example.

3. Because concurrent basins are of interest, and these are shown in figure 92 for this example, consider the steps in section 5.4.4.2. Expand the isohyetal pattern to cover the primary and concurrent basins as shown in figure 93.

3-1. The TAF from the procedure outlined in section 5.5.3 for the primary basin gives 1.35; and must be determined for each concurrent basin (sect. 5.4.3.2). Since computation of the TAF was detailed in step 6 of section 5.5.3, it was not repeated here. The TAF for each concurrent basin is divided by the TAF for the primary basin. Note that because the total area of primary plus concurrent basins exceeds 500 mi^2, the maximum adjustment of 0.25 from figure 66 is used to adjust the TAF in the concurrent basins. Refer to table 19 for these results.

3-2. To determine the warping factor, W, it is first necessary to convert the 2-yr 24-hr analysis in figure 94 (taken from fig. 59) to a percentage analysis. The center of the isohyetal pattern in figure 93 is 3.4 in. in figure 94. Dividing all the 2-yr 24-hr isohyets in figure 94 by 3.4 results in the isopercental analysis shown in figure 95.

The primary basin and each subbasin in figure 95 were planimetered to obtain average percentage values; 1.139 for the primary basin, 0.902 for subbasin A, 0.843 for subbasin B, 1.042 for subbasin C, and 0.829 for subbasin D. Taking the inverse of those average percentage values gives the respective values for W as listed in column 4 of table 19.

3-3. Since the pattern was not displaced in the example it is not necessary to adjust the isohyet values.

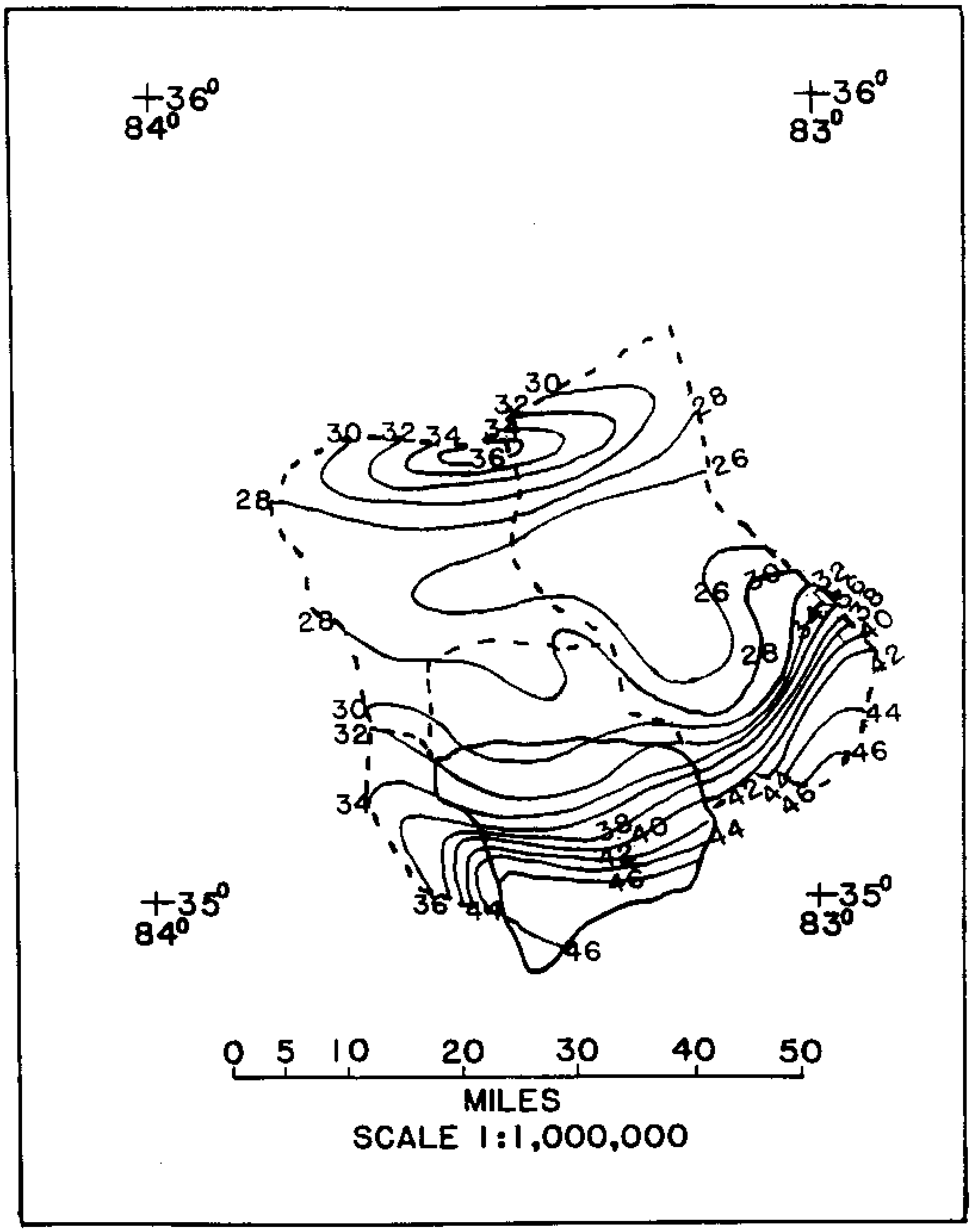


Figure 94.--2-yr 24-hr analysis that covers primary and concurrent basins (Reproduced from fig. 59). Note that all values are in tenths of an inch and have been multiplied by 10.

3-4. Multiply the total PMP isohyets in step 1-2 in each of the concurrent basins by the respective adjusted TAF's. Planimeter the adjusted isohyets to determine the incremental total volume for each concurrent basin, which is designated as V_x. Values of V_x for this example are summarized in column 4 of table 19.

3-5. Graphically multiply the orographically adjusted isohyet labels in step 3-4 by the isopercental analysis from step 3-2 (fig. 95).

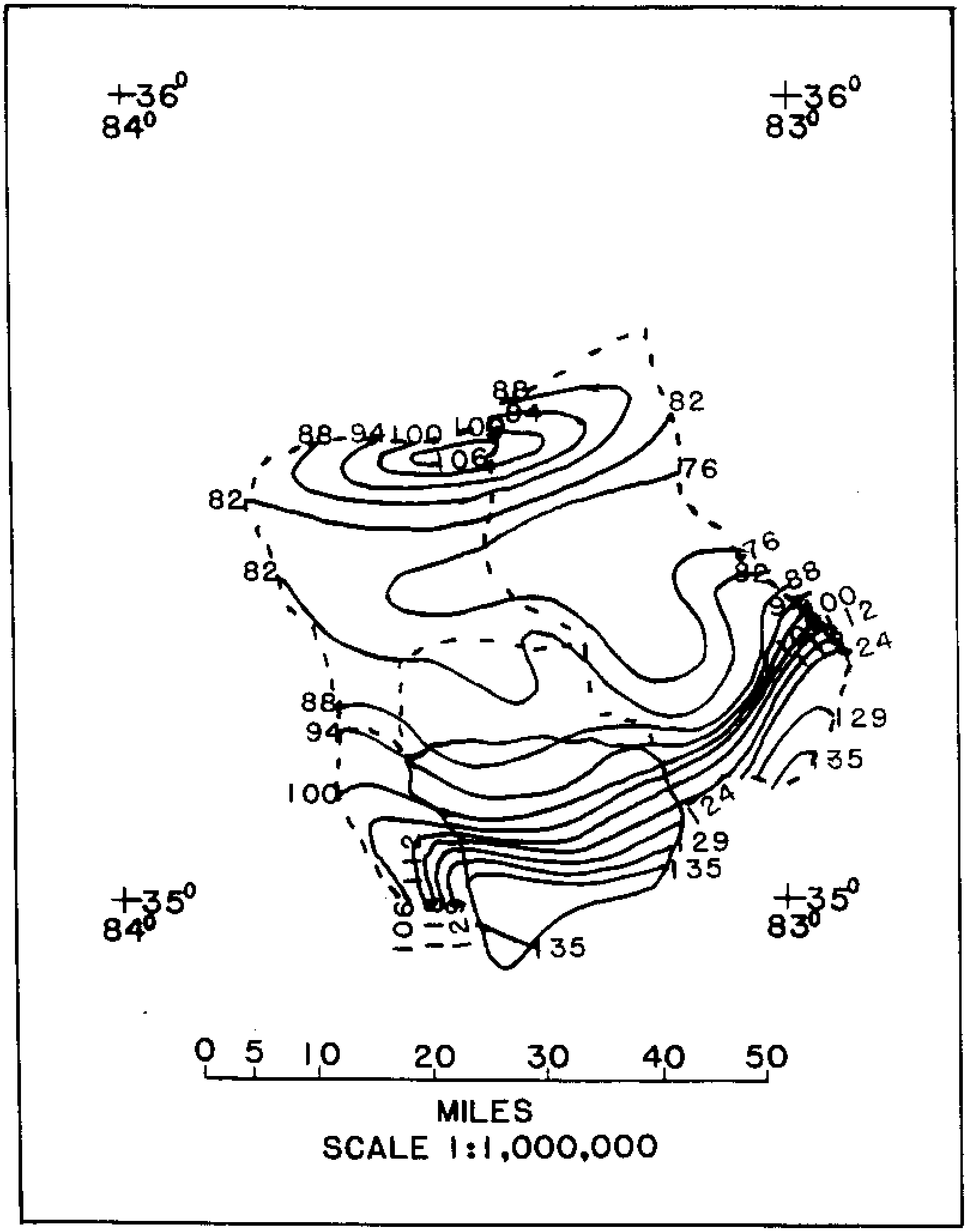


Figure 95.--Isopercental analysis of 2-yr 24-hr precipitation for primary and concurrent basins.

3-6. Analyze the results in step 3-5, as shown in figure 96 for this example. Note the discontinuities along basin boundaries. Adjust to maintain the volume given by the respective V_x for each basin in step 3-4 by multiplying the isohyets in figure 96 by the respective warping factor, W, from step 3-2. The warped isohyetal pattern adjusted by W and smoothed to remove the discontinuities is shown in figure 97. If the smoothing is believed to

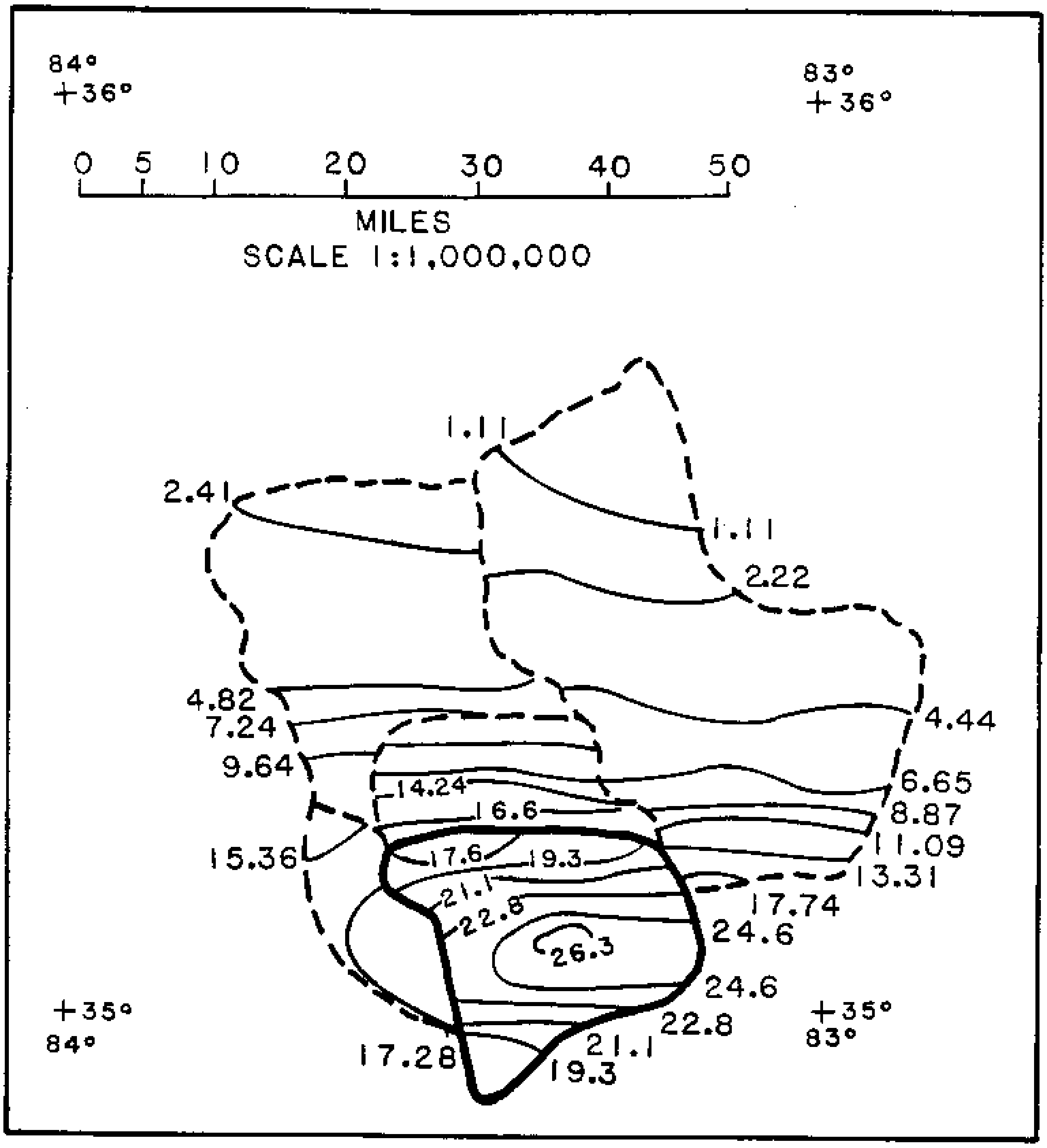


Figure 96.--Warped orographically adjusted pattern of total PMP (in.), first 6-hr increment for primary and concurrent basins. Notice the discontinuities of interfaces of subbasins.

Table 19.--Total volumetric precipitation for Little Tennessee River (subbasin 8) and concurrent basins, first 6-hr increment

Basin	Area (mi^2)	TAF	Adjusted TAF*	Total Volumetric Precipitation (V_x)	W
8	295	1.35	-	6771.62	0.878
A	655	1.10	0.81	2917.31	1.109
B	141	1.00	0.74	1620.77	1.186
C	91	1.15	0.85	1248.26	0.960
D	389	1.05	0.78	1805.43	1.206

* For concurrent basins in the mountainous east, the adjusted TAF is the TAF for the concurrent basin divided by the TAF for the primary basin; in this case TAF for the primary basin is 1.35.

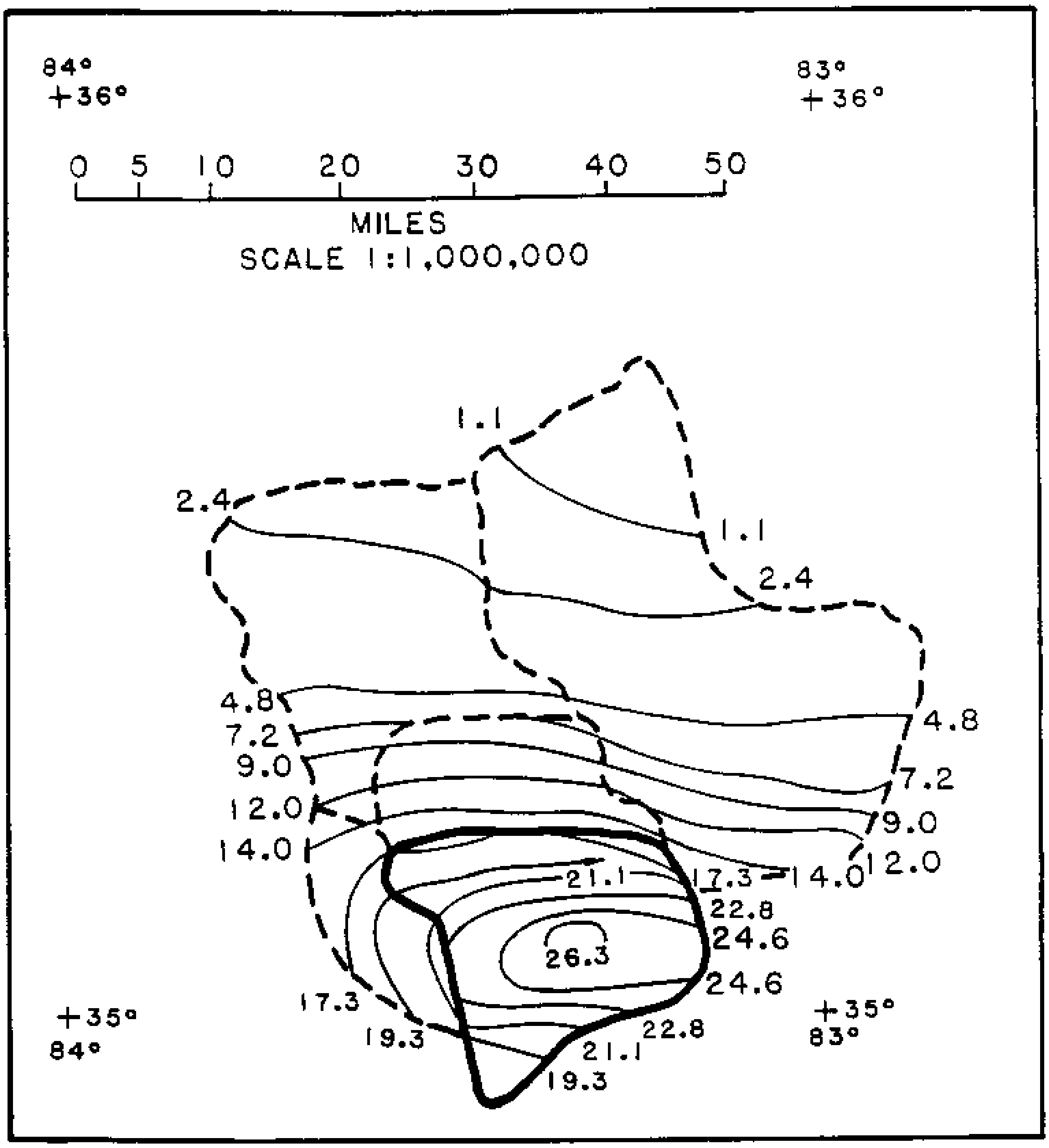


Figure 97.—Smoothed pattern of total PMP (in.), first 6-hr increment.

significantly change the volume, it may be necessary to replanimeter and adjust the isohyet values to maintain the volume, V_x (note that the adjusted isohyets have decimal values; it is not recommended to evaluate the pattern for whole numbers).

The values for TAF, W, and V_x for the second 6-hr increment are given in table 20, while figures 98 and 99 show the orographically adjusted warped and the smoothed patterns after modifying by W, respectively, for the second increment. Similar treatment (not shown here) is necessary for the other 6-hr increments to complete the example.

This example attempts to show the treatment recommended for concurrent basins, as well as the overall determination of areally distributed PMP for a basin in the mountainous east.

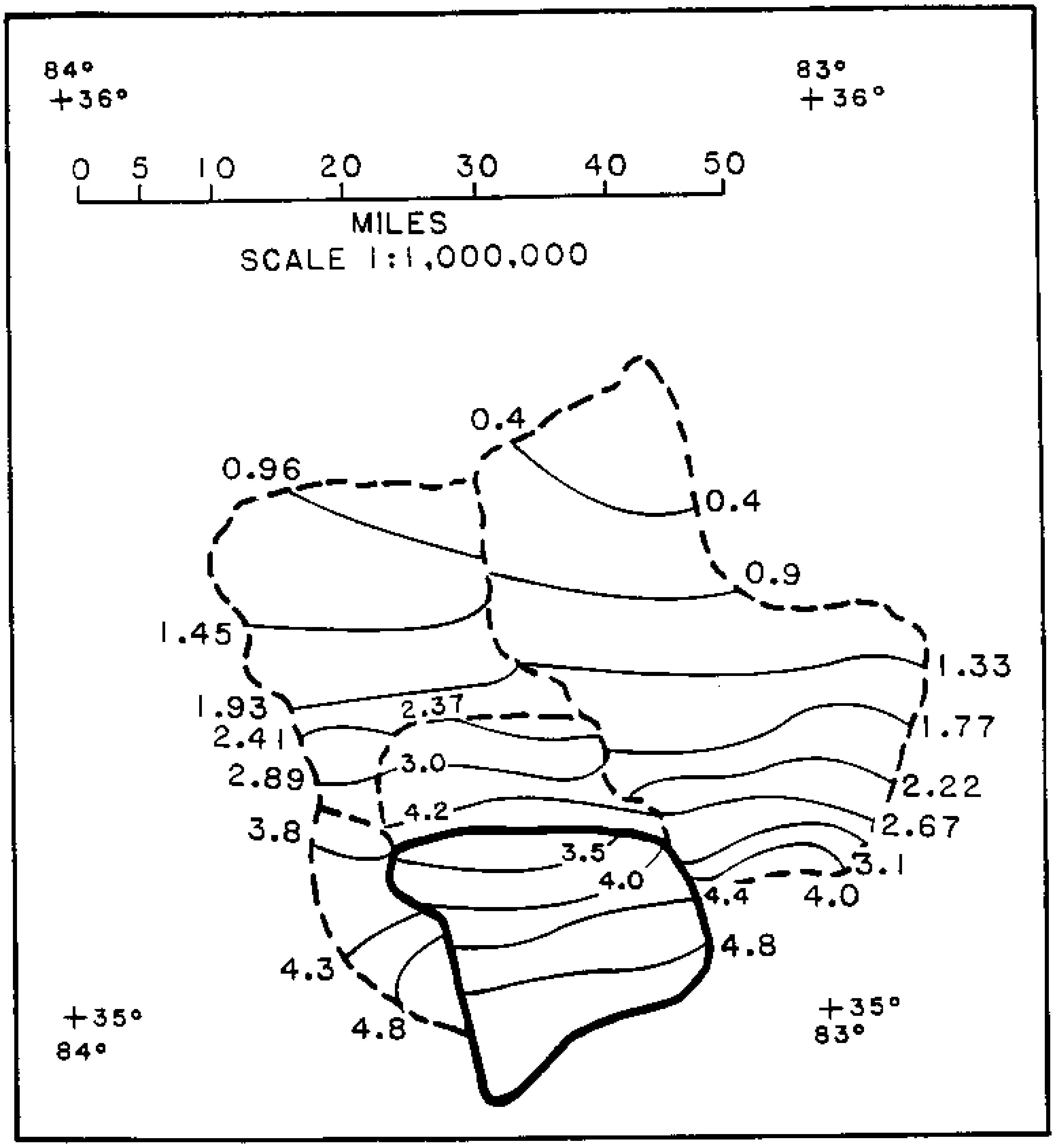


Figure 98.--Warped orographically adjusted pattern of total PMP (in.), second 6-hr increment.

3-7. Since both the primary and concurrent basins are located in the mountainous eastern portion of the watershed and are considered "rough," the smoothed total PMP isohyetal values obtained in step 3-6 are multiplied by 0.58 to obtain the areal distribution of TVA precipitation. These results are not shown.

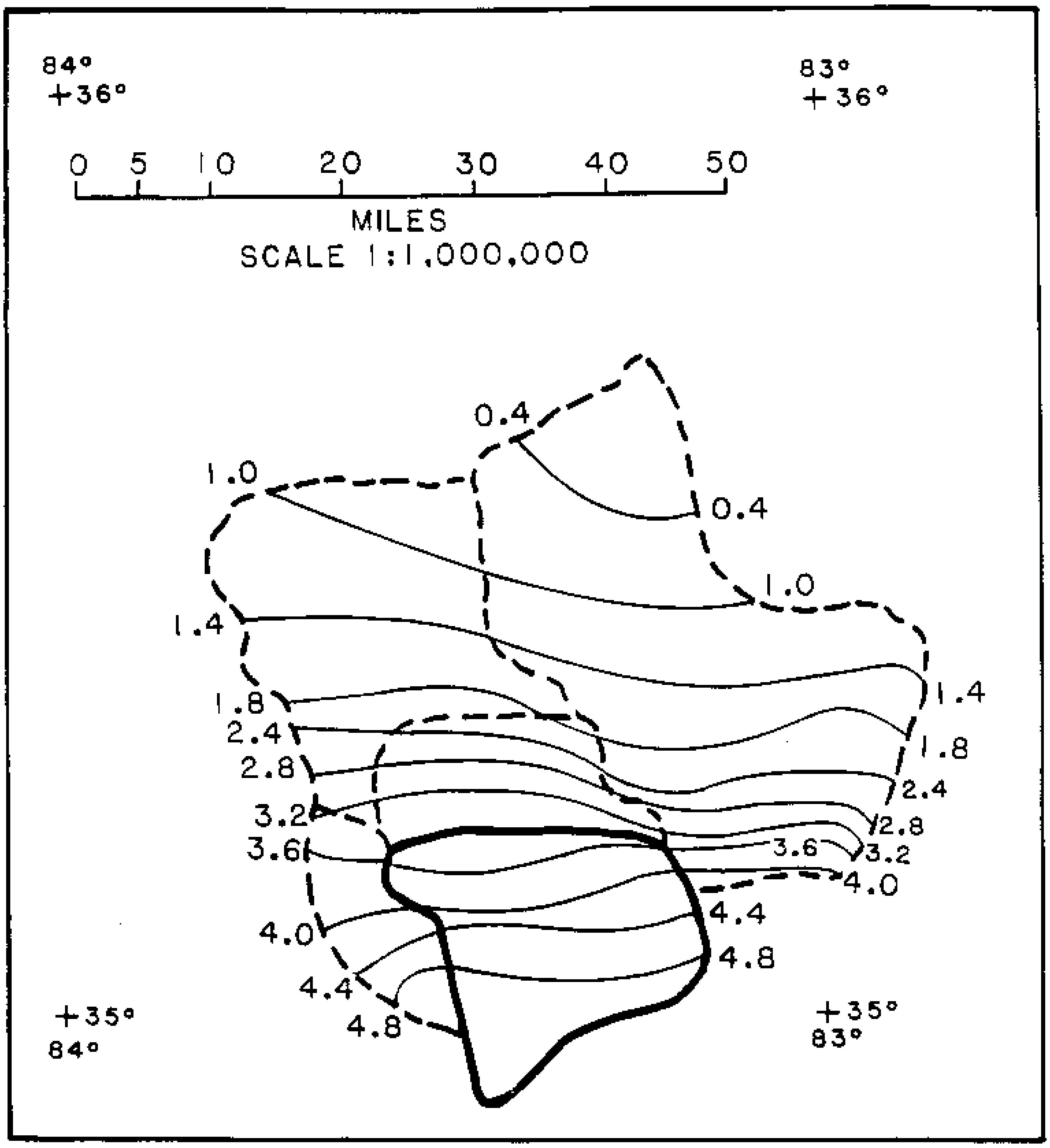


Figure 99.--Smoothed pattern of total PMP (in.), second 6-hr increment.

Table 20.--Total volumetric precipitation for Little Tennessee River (subbasin 8) and concurrent basins, second 6-hr increment

Basin	Area (mi^2)	TAF	Adjusted TAF*	Total Volumetric Precipitation (V_x)	W
8	295	1.35	-	1291.91	0.878
A	655	1.10	0.81	827.35	1.109
B	141	1.00	0.74	369.85	1.186
C	91	1.15	0.85	266.69	0.96
D	389	1.05	0.78	516.57	1.206

* For concurrent basins in the mountainous east, the adjusted TAF is the TAF for the concurrent basin divided by the TAF for the primary basin; in this case TAF for the primary basin is 1.35.

Table 21.—Terrain and orographic factors for basins located in mountainous and nonmountainous east portions of the Tennessee River watershed.

Subbasin	Terrain Stimulation Factor (TSF)	Broadscale Factor (BOF)	Total Adjustment Factor (TAF)
1	0.92	0.10	1.00
2	0.93	0.10	1.05
3	0.93	0.15	1.10
4	0.96	0.25	1.20
5	1.05	0.15	1.20
6	0.95	0.20	1.15
6A	1.07	0.25	1.30
7	0.90	0.15	1.05
8	1.05	0.30	1.35
9	0.91	0.15	1.05
10	1.00	0.10	1.10
11	0.99	0.10	1.10
12	1.11	0.20	1.30
13	0.97	0.05	1.00
14	1.04	0.00	1.05
15	1.05	0.00	1.05
16	1.02	0.05	1.05
17	1.09	0.10	1.20
1C	1.05	0.00	1.05
2C	1.08	0.00	1.10
3C	1.04	0.00	1.05
4C	1.05	0.00	1.05
5C	1.05	0.00	1.05

6. SPECIFIC BASIN ESTIMATES FOR PMP AND TVA PRECIPITATION

This section includes PMP and TVA precipitation estimates for 26 specific basins with areas greater than 100 mi^2 that were evaluated in the original TVA study (Schwarz and Helfert 1969). Figure 100 shows the location of the 23 basins that are in the eastern part of the basin. A description of the related topography can be found in chapter 1.

The procedures that were used to derive these estimates are those discussed in sections 5.3.1 and 5.3.2. Table 21 lists factors (broadscale orographic, terrain stimulation, and total adjustment). Note that the broadscale and total factors are rounded to the nearest 0.05. Table 22 lists the PMP and TVA precipitation estimates for the 26 basins and it should be noted that the results produced by procedures in this report differ from those in HMR No. 45. The results in table 22 supersede all previous results given for these basins. Finally, one should note that the values in table 22 are storm-areally averaged PMP and TVA precipitation values and are not areally distributed.

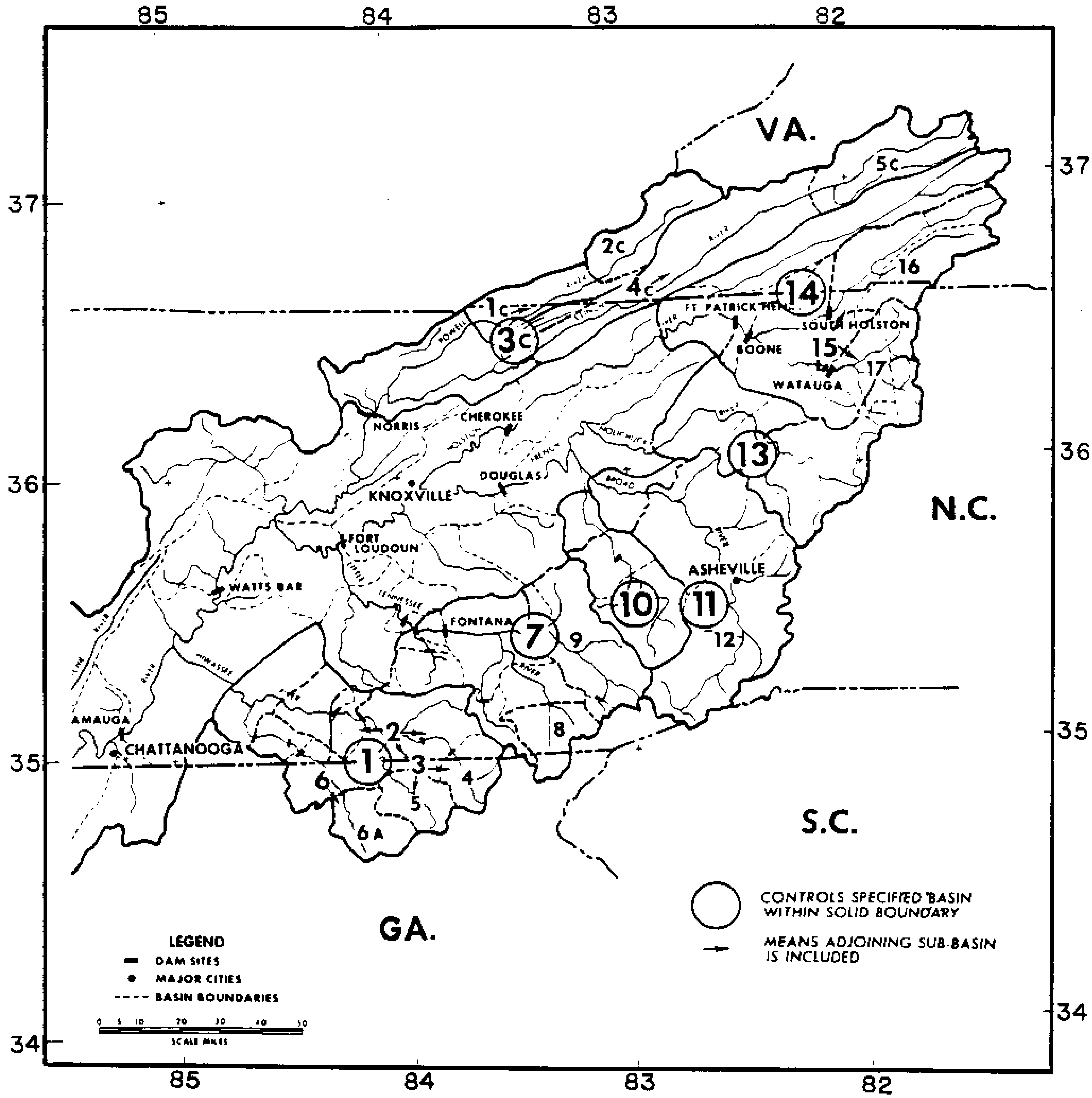


Figure 100.—Locations for subbasins given in table 21 and 22.

Table 22.--Accumulated PMP and TVA Precipitation (in.) for selected drainages*

Subbasin	Precip. Type	6	12	18	24	30	36	42	48	54	60	66	72
A. Hiwassee River Drainages													
		Duration (hr.)											
Hiwassee R. above Charleston, TN	PMP	11.5	14.9	17.2	18.8	20.1	21.1	21.9	22.6	23.1	23.6	24.1	24.5
(Subbasin 1, fig. 100) 2,189 mi²	72-hr TVA	5.3	8.1	9.7	10.9	11.7	12.2	12.7	13.1	13.5	13.8	14.0	14.2
Hiwassee R. above Austral, TN	PMP	13.7	16.9	19.1	20.8	22.0	23.0	23.8	24.5	25.1	26.7	26.2	26.7
(Subbasin 2, fig. 100) 1,228 mi²	72-hr. TVA	5.5	8.2	10.1	11.5	12.6	13.4	13.9	14.3	14.6	14.9	15.2	15.4
Hiwassee R. above Hiwassee Dam, TN	PMP	15.2	18.7	21.2	23.0	24.4	25.4	26.3	26.9	27.5	28.0	28.5	28.9
(Subbasin 3, fig. 100) 968 mi²	72-hr. TVA	6.0	9.0	11.0	12.5	13.6	14.5	15.1	15.6	16.0	16.3	16.5	16.7
Hiwassee R. above Chatuge Dam, NC	PMP	22.6	26.8	29.5	31.5	32.9	34.1	35.0	35.8	36.4	37.0	37.6	38.1
(Subbasin 4, fig. 100)	24-hr. TVA	9.0	13.7	16.2	18.1								
189 mi²	72-hr. TVA	8.0	12.6	14.9	16.6	17.9	18.9	19.7	20.3	20.8	21.3	21.7	22.0
Nottely R. above Nottely Dam, GA	PMP	22.1	26.4	28.9	30.8	32.3	33.4	34.3	35.0	35.7	36.2	36.7	37.2
(Subbasin 5, fig. 100)	24-hr. TVA	9.9	13.6	16.0	17.8								
214 mi²	72-hr. TVA	7.8	12.2	14.6	16.4	17.6	18.6	19.4	20.0	20.5	20.9	21.2	21.5
Ocoee R. above Ocoee	PMP	17.9	21.7	24.2	25.9	27.3	28.4	29.3	30.1	30.0	31.5	32.1	32.7
Ocoee Dam #1, TN (Subbasin 6, fig 100) 595 mi²	72-hr. TVA	7.1	10.3	12.6	14.2	15.4	16.4	17.1	17.7	18.1	18.4	18.7	18.9
Tocca R. above Blue Ridge Dam, GA	PMP	24.2	28.9	31.6	33.6	35.1	36.3	37.3	38.2	39.0	39.8	40.6	41.3
(Subbasin 6A, fig. 100)	24-hr. TVA	10.4	14.5	17.2	19.3								
232 mi²	72-hr. TVA	8.8	14.0	16.5	18.2	19.5	20.6	21.6	22.0	22.5	23.0	23.5	23.9

*Note: The PMP and TVA precipitation values in Table 22 represent <u>storm averaged</u> values while the PMP and TVA precipitation values in Table 4-1 of HMR No. 45 are basin-averaged values and therefore cannot be compared directly.

Table 22.--Accumulated PMP and TVA Precipitation (in.) for selected drainages (Continued)

Subbasin	Precip. Type	Duration (hr.) 6	12	18	24	30	36	42	48	54	60	66	72
		B. Little Tennessee River Drainages											
Little Tennessee R. Fontana Dam, NC	PMP	12.7	16.1	18.4	20.0	21.3	22.3	23.1	23.8	24.4	24.9	25.4	25.8
(Subbasin 7, fig. 100) 1,571 mi^2	72-hr. TVA	5.3	8.0	10.0	11.5	12.5	13.3	13.9	14.3	14.6	14.7	14.8	14.9
Little Tennessee R. above Franklin, NC	PMP	23.5	27.8	31.2	33.5	35.0	36.2	37.2	38.0	38.7	39.4	40.0	40.6
(Subbasin 8, fig. 100)	24-hr. TVA	10.4	14.5	17.2	19.3								
295 mi^2	72-hr. TVA	8.7	13.7	16.2	18.0	19.4	20.4	21.2	21.9	22.4	22.8	23.2	23.5
Tuckasegee R. above. Bryson City, NC	PMP	15.8	19.1	21.3	23.0	24.3	25.3	26.1	26.8	27.4	28.0	28.4	28.8
(Subbasin 9, fig. 100) 655 mi^2	72-hr. TVA	6.4	9.6	11.4	12.6	13.6	14.4	15.0	15.4	15.8	16.1	16.4	16.6
		C. Pigeon and French Broad River Drainages											
Pigeon R. above Newport, TN	PMP	16.1	19.5	21.8	23.5	24.8	25.8	26.7	27.4	28.0	28.6	29.1	29.6
(Subbasin 10, fig. 100) 666 mi^2	72-hr. TVA	6.2	9.6	11.6	13.0	14.0	14.7	15.4	15.9	16.3	16.6	16.9	17.1
French Broad R. above Newport, TN	PMP	12.5	16.0	18.3	20.0	21.3	22.3	23.1	23.8	24.4	24.9	25.4	25.8
(Subbasin 11, fig. 100) 1,858 mi^2	72-hr. TVA	5.3	8.10	10.0	11.5	12.5	13.3	13.9	14.3	14.6	14.7	14.5	14.5

Table 22.--Accumulated PMP and TVA Precipitation (in.) for selected drainages (Continued)

Subbasin	Precip. Type	Duration (hr.) 6	12	18	24	30	36	42	48	54	60	66	72
A. Hiwassee River Drainages													
French Broad R. above Asheville, NC	PMP	17.9	22.4	25.2	27.2	28.7	29.9	30.9	31.7	32.4	33.0	33.6	34.2
(Subbasin 12, fig. 100) 945 mi^2	72-hr. TVA	7.2	10.7	13.1	14.9	16.2	17.2	18.0	18.5	19.0	19.4	19.6	19.8
D. Holston and Nolichucky River Drainages													
Nolichucky R. above Nolichucky Dam, TN	PMP	10.9	14.0	16.0	17.4	18.6	19.6	20.4	21.0	21.5	22.0	22.4	22.8
(Subbasin 13, fig. 100) 1,183 mi^2	72-hr. TVA	4.7	7.1	8.8	10.0	10.9	11.6	12.0	12.4	12.7	12.9	13.1	13.2
Holston R. above Surgoinsville, TN	PMP	10.1	13.0	15.1	16.6	17.7	18.7	19.4	20.0	20.5	21.0	21.4	21.7
(Subbasin 14, fig. 100) 2,874 mi^2	72-hr. TVA	4.5	6.7	8.3	9.4	10.3	11.0	11.5	11.9	12.2	12.4	12.5	12.6
Holston R. above Fort Patrick Henry, TN	PMP	11.3	14.4	16.6	18.2	19.4	20.3	21.1	21.7	22.2	22.6	23.0	23.4
(Subbasin 15, fig. 100) 1,903 mi^2	72-hr. TVA	5.0	7.3	8.9	10.2	11.1	11.8	12.3	12.7	13.0	13.3	13.4	13.5
Holston R. above South Holston Dam, TN	PMP	14.6	17.7	20.0	21.6	22.7	23.7	24.4	25.1	25.7	26.2	26.7	27.1
(Subbasin 16, fig. 100) 703 mi^2	72-hr. TVA	5.6	8.6	10.3	11.6	12.4	12.9	13.4	13.8	14.2	14.6	14.8	15.0

Table 22.--Accumulated PMP and TVA Precipitation (in.) for selected drainages (Continued)

Subbasin	Precip. Type	Duration (hr.) 6	12	18	24	30	36	42	48	54	60	66	72
Watauga R. above Watauga Dam, TN	PMP	17.9	21.8	24.2	26.0	27.2	28.3	29.1	29.8	30.5	31.2	31.7	32.2
(Subbasin 17, fig. 100) 468 mi^2	72-hr. TVA	6.6	10.1	12.1	13.7	14.5	15.2	15.8	16.3	16.8	17.2	17.5	17.7
Powell R. above Arthur, TN	PMP	14.4	17.4	19.6	21.2	22.3	23.2	23.9	24.5	25.1	25.6	26.1	26.6
(Subbasin 1C, fig. 100) 684 mi^2	72-hr. TVA	5.5	8.4	10.1	11.3	12.1	12.7	13.2	13.6	13.9	14.2	14.5	14.7
Powell R. above Jonesville, TN	PMP	16.6	19.8	22.0	23.8	24.8	25.7	26.4	27.0	27.6	28.2	28.7	29.2
(Subbasin 2C, fig. 100) 319 mi^2	72-hr. TVA	6.0	9.2	11.0	12.4	13.5	13.9	14.3	14.7	15.1	15.5	15.9	16.1

Table 22.--Accumulated PMP and TVA Precipitation (in.) for selected drainages (Continued)

Subbasin	Precip. Type	Duration (hr.) 6	12	18	24	30	36	42	48	54	60	66	72
E. Clinch River Drainages													
Clinch R. above Norris Dam, TN	PMP	10.0	12.8	15.0	16.6	17.5	18.3	19.0	19.6	20.1	20.6	21.1	21.6
(Subbasin 3C, fig. 100) 2,912 mi^2	72-hr. TVA	4.4	6.8	8.2	9.2	9.8	10.2	10.6	11.0	11.3	11.6	11.8	11.9
Clinch R. above Tazewell, TN	PMP	11.9	14.9	17.1	18.7	19.5	20.3	21.1	21.8	22.4	23.0	23.4	23.8
(Subbasin 4C, fig. 100) 1,474 mi^2	72-hr. TVA	4.9	7.5	9.1	10.2	10.9	11.4	11.8	12.2	12.5	12.8	13.0	13.2
Clinch R. above Cleveland, TN	PMP	14.7	17.6	19.6	21.3	22.4	23.2	24.0	24.6	25.2	25.7	26.1	26.5
(Subbasin 5C, fig. 100) 528 mi^2	72-hr. TVA	5.5	8.4	10.1	11.3	12.1	12.7	13.1	13.5	13.9	14.3	14.5	14.7
F. Western Basins													
Duck R. Drainage 1,208 mi^2	PMP	12.7	15.8	18.1	20.1	21.3	22.3	23.2	23.8	24.3	24.8	25.2	25.6
	72-hr. TVA	6.8	8.5	9.7	10.8	11.4	12.0	12.5	12.8	13.0	13.2	13.4	13.6
Emory R. Drainage 798 mi^2	PMP	14.7	17.5	19.5	21.2	22.7	23.9	24.6	25.3	25.9	26.4	26.9	27.5
	72-hr. TVA	5.2	8.6	10.2	11.3	12.0	12.5	12.9	13.3	13.7	14.0	14.3	14.6
Obed R. Drainage 518 mi^2	PMP	16.4	19.5	22.0	23.7	24.8	25.8	26.6	27.2	27.8	28.4	28.9	29.4
	72-hr. TVA	5.6	8.8	10.9	12.1	12.9	13.5	13.9	14.3	14.7	15.0	15.3	15.6

7. ANTECEDENT RAINFALL

7.1. Introduction

Antecedent rains are important in determining the size of a flood that occurs on a particular basin. HMR No. 41 (Schwarz 1965) develops antecedent rainfall criteria for large-size basins above Chattanooga. In this report the concern is with antecedent rainfall both for small basins less than 100 mi^2 and for intermediate-size basins ranging from 100 to 3,000 mi^2. For small basins, antecedent rainfall is applied to maximum 24-hr rains, while for the intermediate size basins, conditions prior to 3-day maximum rains are required.

The antecedent rainfall amounts at the TVA precipitation level are intended to be conditions that normally occur prior to significant rains and are selected with the intent that their use does not change the probability of the total event. Thus, if a 3-day antecedent rain is added to a 3-day TVA rain with 3 intervening rainless days, the intention is that the probability of the 9-day event is about the same as that of the 3-day TVA precipitation event. When adopting antecedent conditions for the PMP storm, the condition of equal probability is relaxed.

The study of antecedent rainfall is broken into two separate studies: (1) rainfall antecedent to 24-hr intense small-basin PMP and TVA precipitation, and (2) rainfall antecedent to 3-day PMP and TVA precipitation for larger basins.

Antecedent criteria presented in this chapter are intended to cover all basins encountered in application of the generalized procedures of chapter 5. For simplicity of application, and to avoid compounding of probabilities, the antecedent rainfall should be uniformly distributed over the basin.

7.2 Conditions Anteceding Maximum 24-hr Rainfall

7.2.1 Data Used in the Analyses

From the months of June through October for the period 1937-1965, daily rainfalls of over 5 and 7 in. were selected from over 600 stations in the Tennessee River watershed. Of the 168 cases exceeding 5 in., June had the lowest number of cases with 17 and September the highest with 45. The rains during the 5 days prior to the day of maximum rainfall were summarized both for cases exceeding 5 in. and for the smaller number of cases exceeding 7 in.

Another set of data consisted of high daily rains within two exceptionally rainy months in the Tennessee River watershed, August 1901 and July 1916. In these two months all stations with daily rainfall of 4 in. or more were summarized, and the rainfall for each of the 5-antecedent days tabulated.

A third set of data are the rains antecedent to extremely intense 24-hr summer rainfalls in and near the Tennessee River watershed. These are perhaps the best indicators for setting rains antecedent to maximum 24-hr values. One problem, however, is that the most intense rains usually are reports from bucket surveys and are, therefore, at locations where the rains for previous days are not reported. However, for 10 such rains the average antecedent rainfall could be estimated from nearby regularly reporting stations.

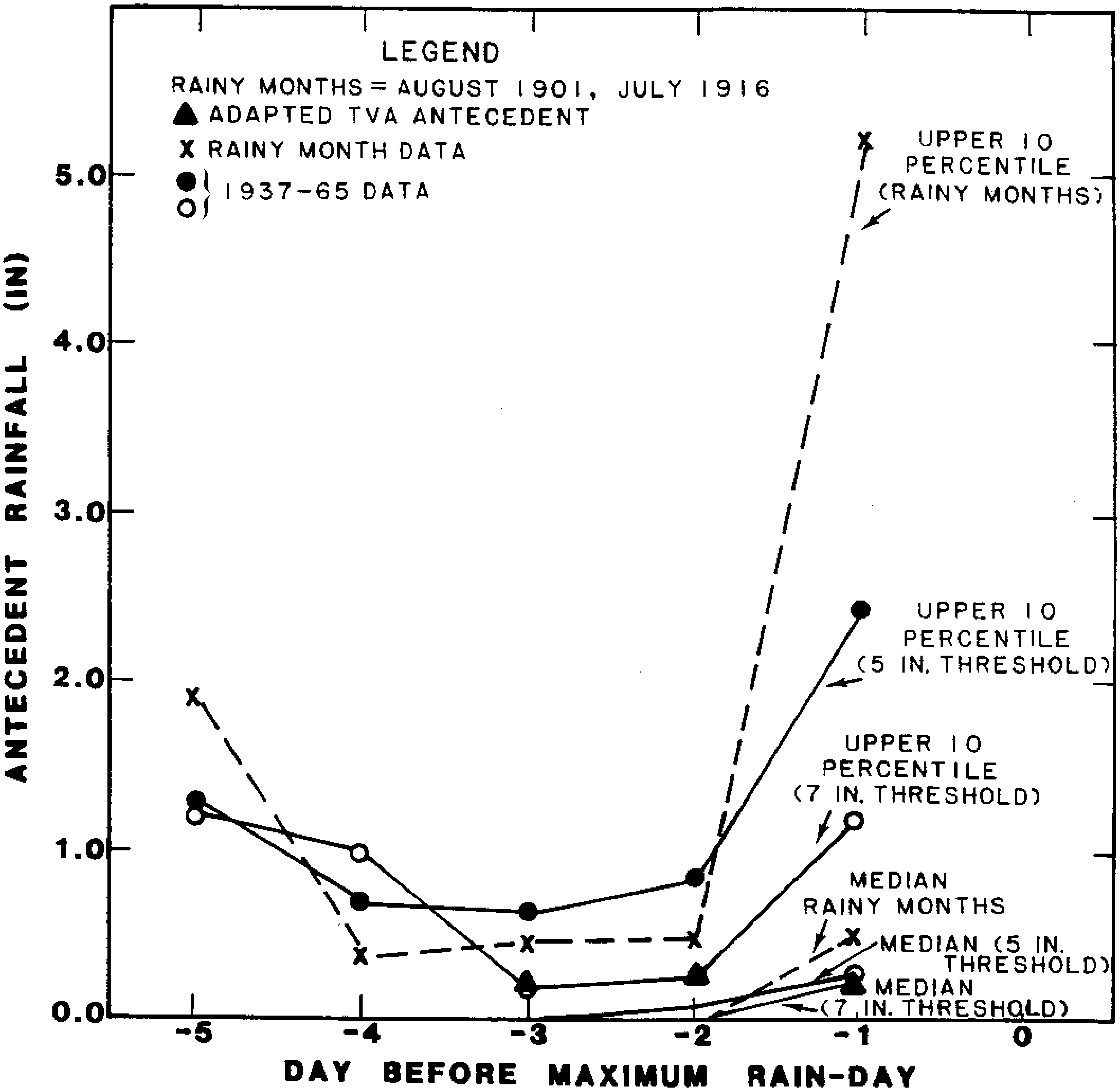


Figure 101.—Antecedent rainfall of moderately heavy rain situations from 1937-1965.

In addition to the 3 sets of data above, frequency analyses were made of daily rains at 4 stations for the months of May through September using 20 yr of data.

7.2.2 Analyses of Antecedent Rainfall Preceding Maximum 24-hr Rainfall

Of the 10 intense rains in the Tennessee River watershed, rains for which antecedent conditions could be evaluated, most were preceded by 2 to 3 days of showery conditions. This appeared to be part of the process of building up to the extreme rain. Antecedent rainfall did not appear to favor significantly any 1 of the 3 days more than the other 2. The average of the daily antecedent rainfall was 0.26 in. on each of the 3 days.

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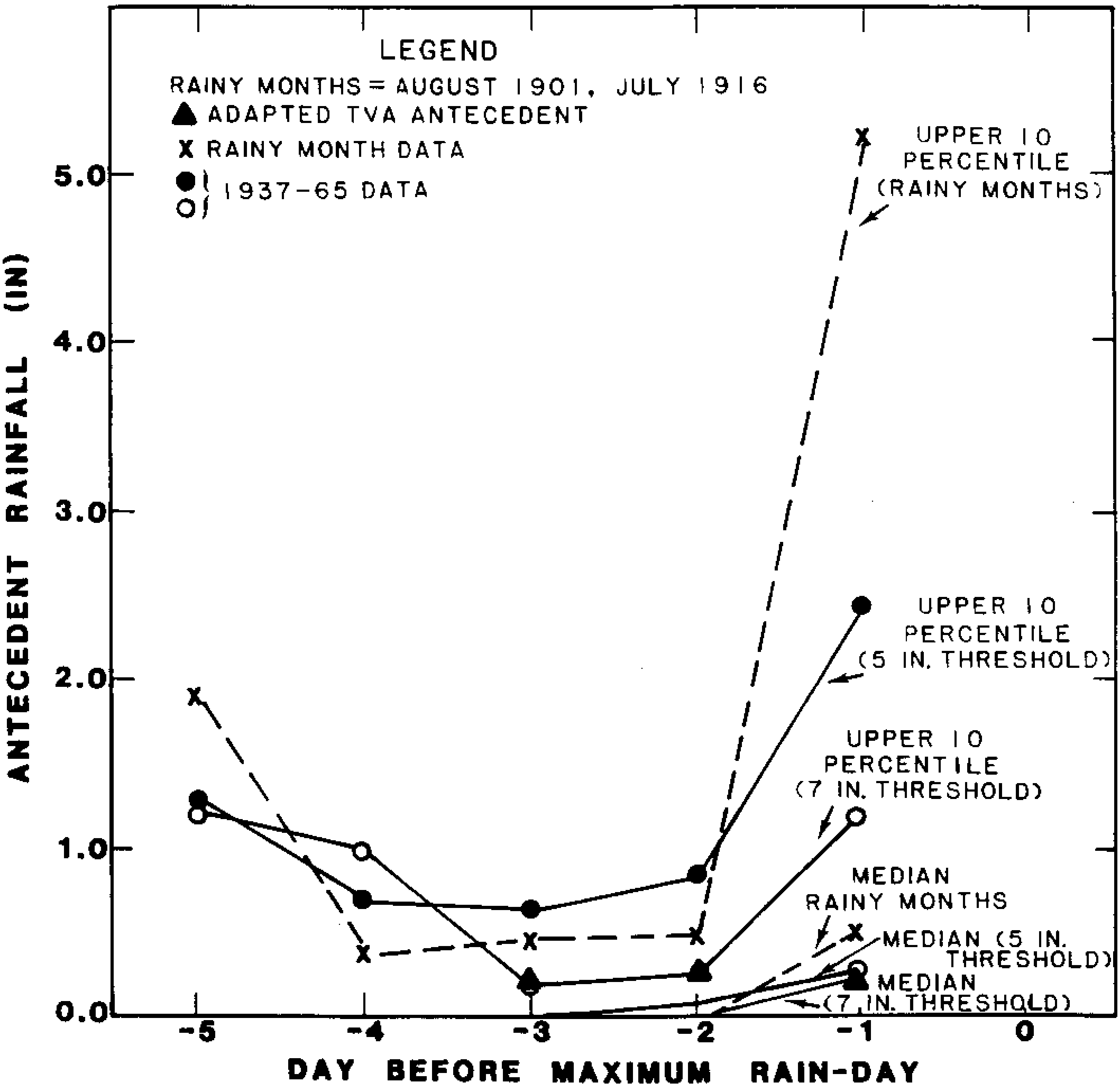

Figure 101.—Antecedent rainfall of moderately heavy rain situations from 1937-1965.

In addition to the 3 sets of data above, frequency analyses were made of daily rains at 4 stations for the months of May through September using 20 yr of data.

7.2.2 Analyses of Antecedent Rainfall Preceding Maximum 24-hr Rainfall

Of the 10 intense rains in the Tennessee River watershed, rains for which antecedent conditions could be evaluated, most were preceded by 2 to 3 days of showery conditions. This appeared to be part of the process of building up to the extreme rain. Antecedent rainfall did not appear to favor significantly any 1 of the 3 days more than the other 2. The average of the daily antecedent rainfall was 0.26 in. on each of the 3 days.

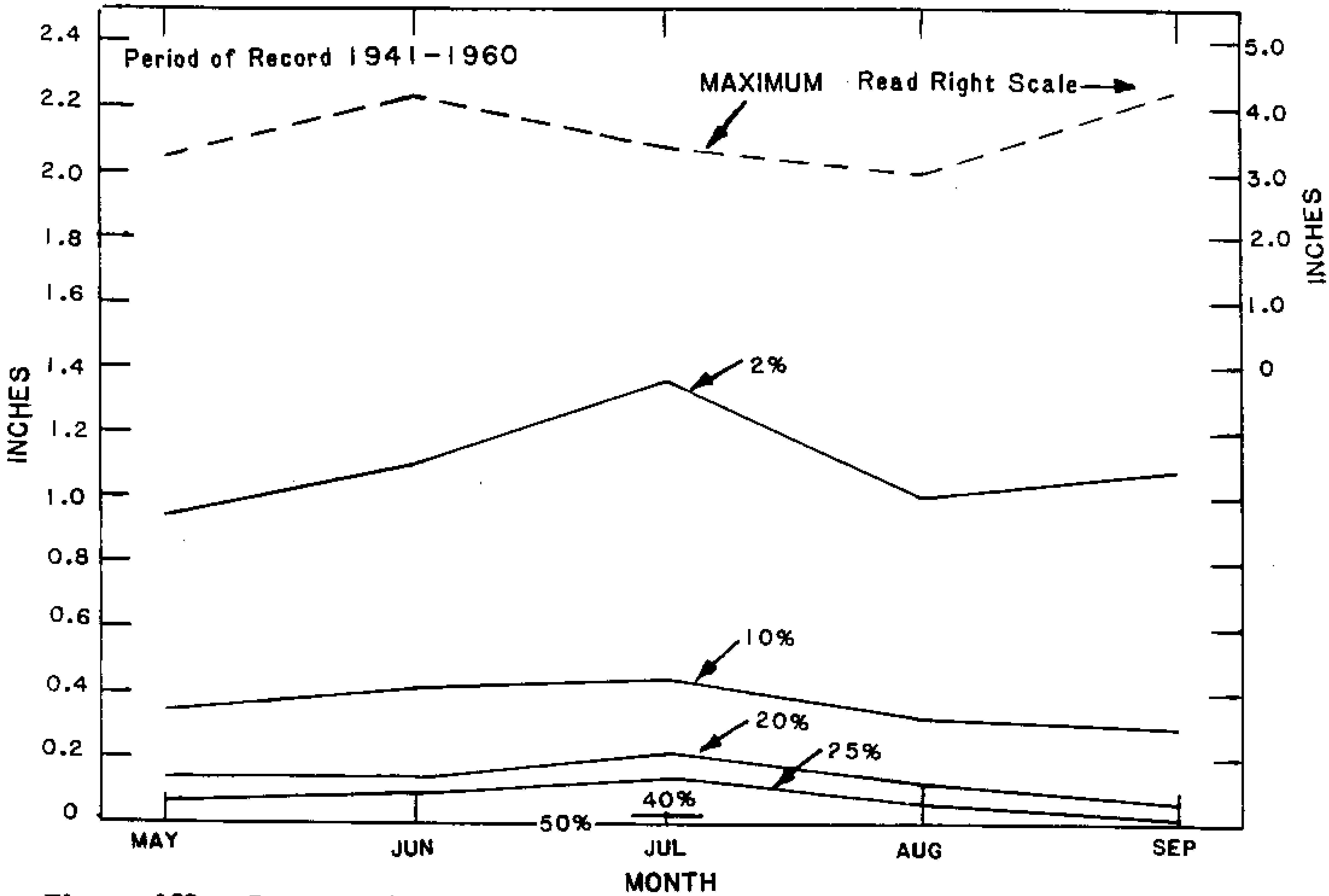

Figure 102.--Percent chance of daily rainfall at Asheville, NC.

Figure 101 shows the results of analyses of the moderately heavy rain situations from the 1937-1965 survey and the two rainy months. Median and upper 10-percentile values resulting from a statistical analysis of each are givén. At the median level of the 7-in. threshold data, the amount of first-day antecedent rainfall did not differ significantly from that of the 5-in. threshold data (0.25 in.). However, for the rarer event (upper 10-percentile) the first-day antecedent rainfall decreased considerably for the 7-in. threshold compared to the 5-in.

The 53 cases of daily rainfall greater than or equal to 4 in. in August 1901 and July 1916 are referred to as "rainy months" data in figure 101. These have antecedent rains comparable to the previous set except at the upper 10-percentile point on the first antecedent day. The median rainfall 1 day prior to large daily amounts is 0.25 in. (fig. 101). This comparison shows that there is some association of rain one day with the next.

The question of dependence of rainfall events can be resolved in part by comparing median rainfall for all days with the median on days prior to large storms. A frequency analysis of a 20-yr daily rainfall record (1941-60) was made at four stations for the months of May through September. Figures 102 through 104 summarize expected daily rainfalls at 3 of the stations, Asheville, Chattanooga, and Memphis for various probability levels. The maximum for the 1941-1960 period is also shown. There is a 50 percent probability of no rain for all 3 stations. The fourth station at Tray Mt. showed questionable data for July and plotted data were not shown.

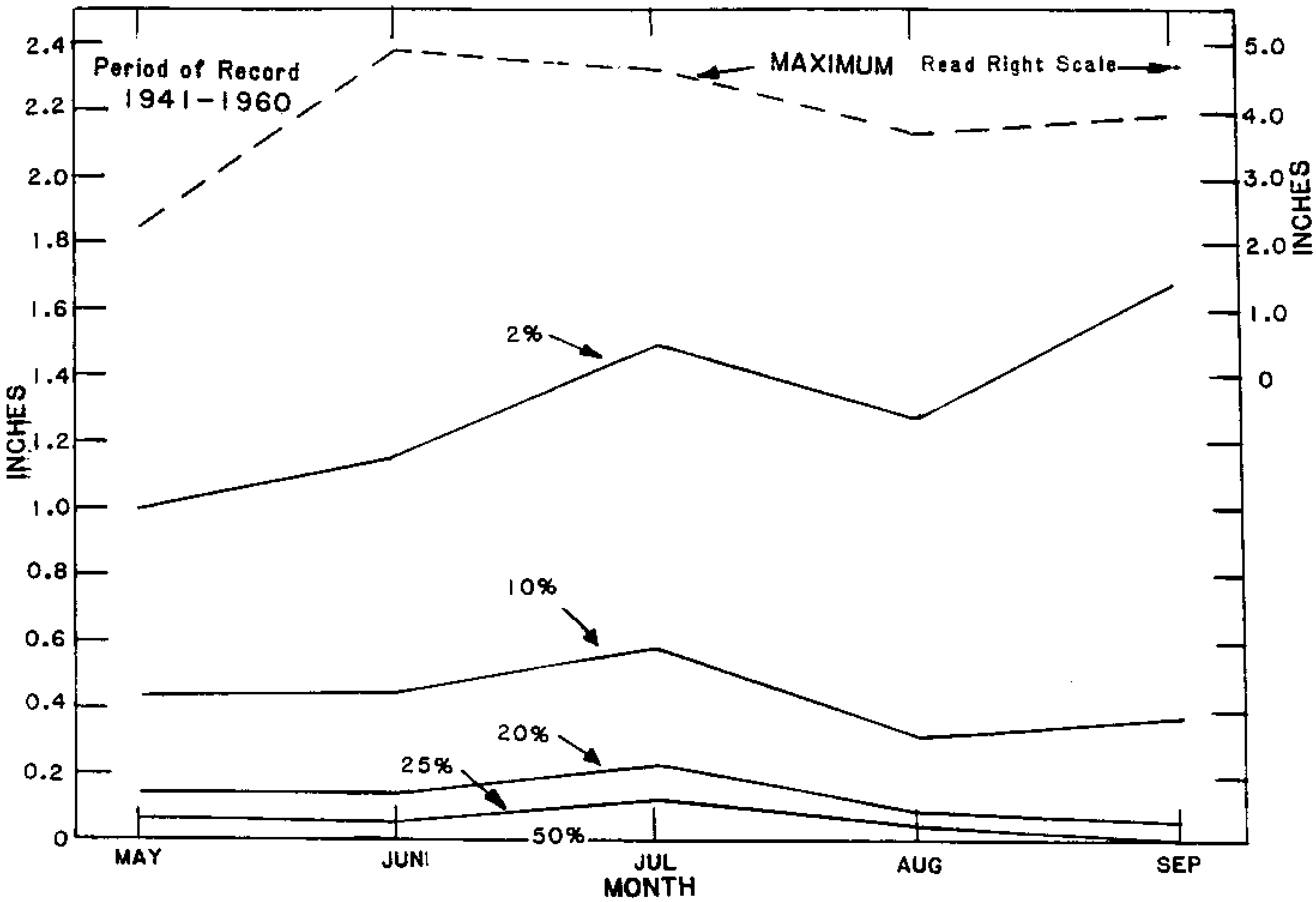

Figure 103.--Percent chance of daily rainfall at Chattanooga, TN.

The interdependence is strong at the 10-percentile level. Table 23 lists the upper 10-percentile values from all daily rainfalls at 4 stations. The May through September average of the upper 10-percentile is 0.45 in., significantly different from the 10-percentile first-day antecedent value of 1.2 and 2.5 in. for the 7- and 5-in. thresholds, respectively.

The analysis discussed above supports the conclusion that rainfall prior to the PMP and TVA 24-hr storm will tend to exceed the average. One reason for this, physically, is persistence of a broadscale synoptic situation favorable for heavy rains. This results in the influx of high moisture into the area so that some shower activity is likely to precede a heavy rain situation.

<u>Adopted values antecedent to maximum 24-hr rain</u>

Antecedent rainfall of 0.25 in. for each of 2-antecedent days preceding the 24-hr TVA storm is recommended for application to all small basin estimates. Such magnitudes are supported both by the conditions preceding extreme summer short-duration rainfalls in the Tennessee River watershed, and the median antecedent conditions preceding the greater number of less extreme, but still large rainfall amounts.

For PMP storms where there is less concern about making the event less probable, more extreme antecedent possibilities are appropriate. An assessment of the highest observed storm rainfall amounts for durations of 48 and 72 hr provides guidance in selecting antecedent rainfall to go with 24-hr PMP over small basins. HMR No. 51 (Schreiner and Riedel 1978) provides such guidance.

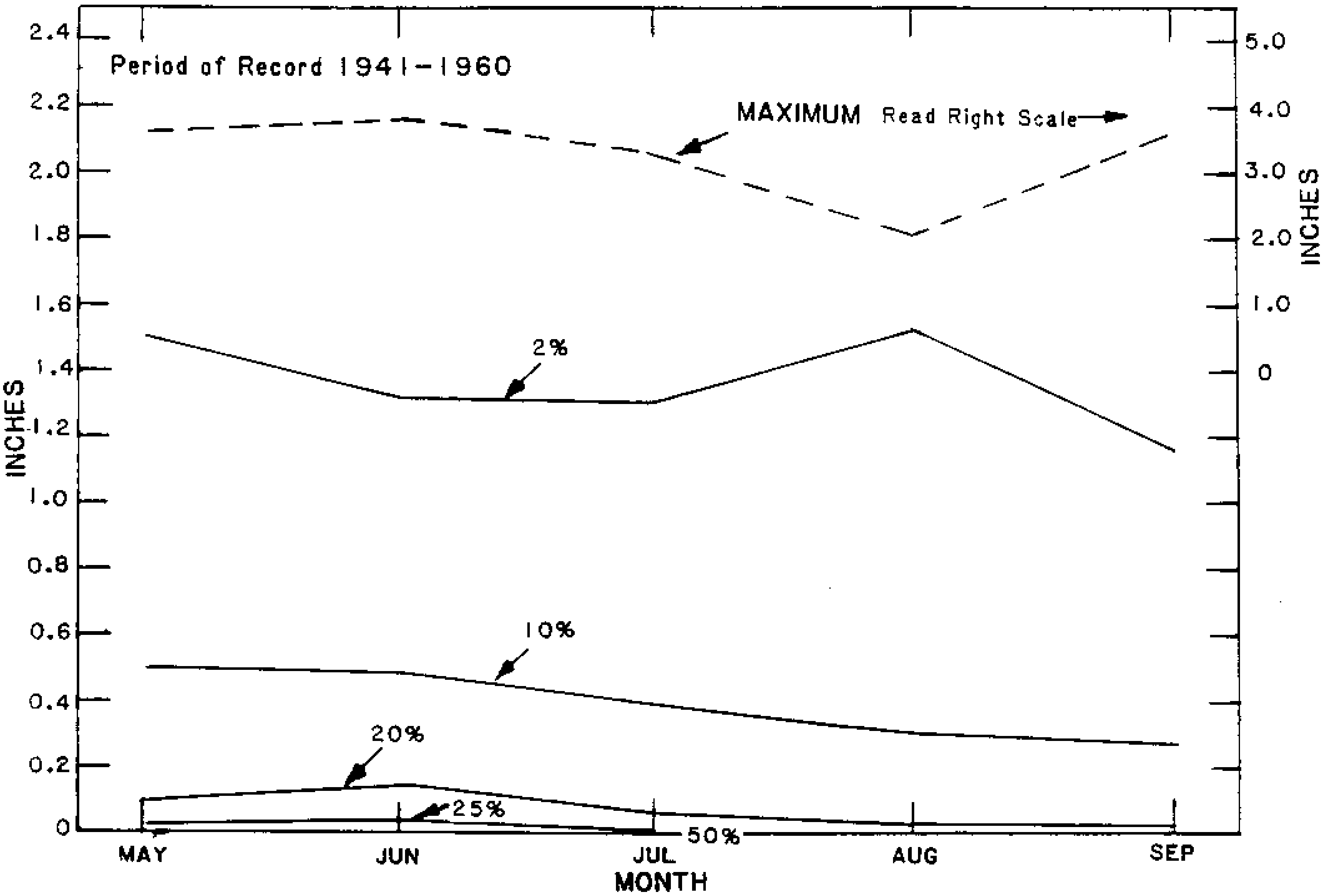

Figure 104.—Percent chance of daily rainfall at Memphis, TN.

Table 23.— Upper 10-percentile of average daily rainfall (in.) (1941-1960)

Station	May	June	July	August	September
Asheville	.34	.41	.44	.32	.29
Chattanooga	.43	.44	.57	.30	.36
Memphis	.50	.49	.39	.30	.27
Tray Mt.	.72	.51	.90	.54	.64
Mean	.50	.46	.56	.36	.39

May-September mean 0.45

Use of the data in HMR No. 51 at 72 hr, combined with a 2 to 1 apportioning of antecedent vs. subsequent (following the precedent of HMR No. 41) results in an adopted 10-percent increment for the first day adjacent to the 24-hr PMP and 2 percent for the second adjacent day. These incremental percentages are to be applied to the 24-hr PMP for the range of basin sizes of 10 to 100 mi^2.

For basin sizes of 1 to 9 mi^2 and a duration of 72 hr, it is recommended that figures 52, 54, and 55 be used to obtain a basin 72 hr 1- to 9-mi^2 PMP. The 72-hr PMP curve in figure 52 needs to be extrapolated from 100 to 1 mi^2. Given the 72-hr PMP for the basin, the incremental percentages of 10 percent increment for the first day adjacent to the 24-hr PMP and 2 percent for the second adjacent day are used for antecedent PMP.

7.3 Conditions Anteceding Maximum 3-Day Rainfall

7.3.1 Introduction

For basins with drainage areas of greater than one hundred to several thousand square miles, sequences of recurring rainfall become increasingly important. With the broadscale meteorological controls remaining relatively fixed, storms may readily repeat over approximately the same area. For very large basins, the January 1937 rainfall in the Tennessee River and Ohio River watersheds is an outstanding example of such an event (Schwarz 1961). For more moderate-size basins in the mountainous eastern portion of the Tennessee River watershed (Tennessee Valley Authority 1961), the repeating, hurricane-associated rainfall in July 1916 provides an excellent example.

The intent in this section is to develop antecedent rainfall criteria applicable to maximum 3-day rains for the PMP level. Two problems are addressed initially. First is the appropriate length of the dry interval between major storms. Second is the magnitude of the antecedent storm with a minimum dry interval. Section 7.3.2 establishes a minimum dry interval of 3 days through examination of antecedent rainfall associated with major U.S. storms. In section 7.3.3., two general approaches are used as guidance in judging what the magnitude should be: (1) statistical guidance from station data, and (2) rainfall antecedent to major U.S. storms. After a minimum dry interval of 3 days was established, a third question was considered. Would the antecedent rain increase significantly if 5 dry days were allowed rather than 3?

7.3.2 Interval Between the Antecedent Storm and the Primary or Main Storm

Previous investigations in HMR No. 35 (Myers 1959), HMR No. 38 (Schwarz 1961), and HMR No. 41 (Schwarz 1965) were directed toward establishing critical meteorological sequences of storms. Figure 105 is an example of the daily changing synoptic (surface weather) transition from one major storm to the second. These hypothetical transition sequences led to the conclusion that 3 days is the minimum interval between major storms for large river basins away from the coast. Many sequences of storms were examined in these studies. Different types of transition from the weather situation at the end of the first storm to that at the beginning of the second storm were examined. It was found that generally 3 days was the minimum time interval required for a reasonable transition from the weather situation at the end of one storm to that at the beginning of the next.

Major rain storms require a storm influx of moisture from a southerly direction, particularly for regions away from coastal areas. The rains are then terminated by colder, drier air flowing from the north or northeast continental regions. The more intense the storm, the greater the inflow of drier air pushing behind the rain producing system and the farther the drier air spreads over the region and across the moisture source region, in this case southward across the Gulf of Mexico. For the gradients and wind flows to reverse themselves and once again provide significant moisture transport to larger basins away from the Gulf of Mexico requires a minimum period of approximately 3 days. As the magnitude of the first storm in the sequence increases, the time interval required to reestablish moisture and stability conditions necessary for a second major storm either increases or the second storm will be reduced in potential. For major

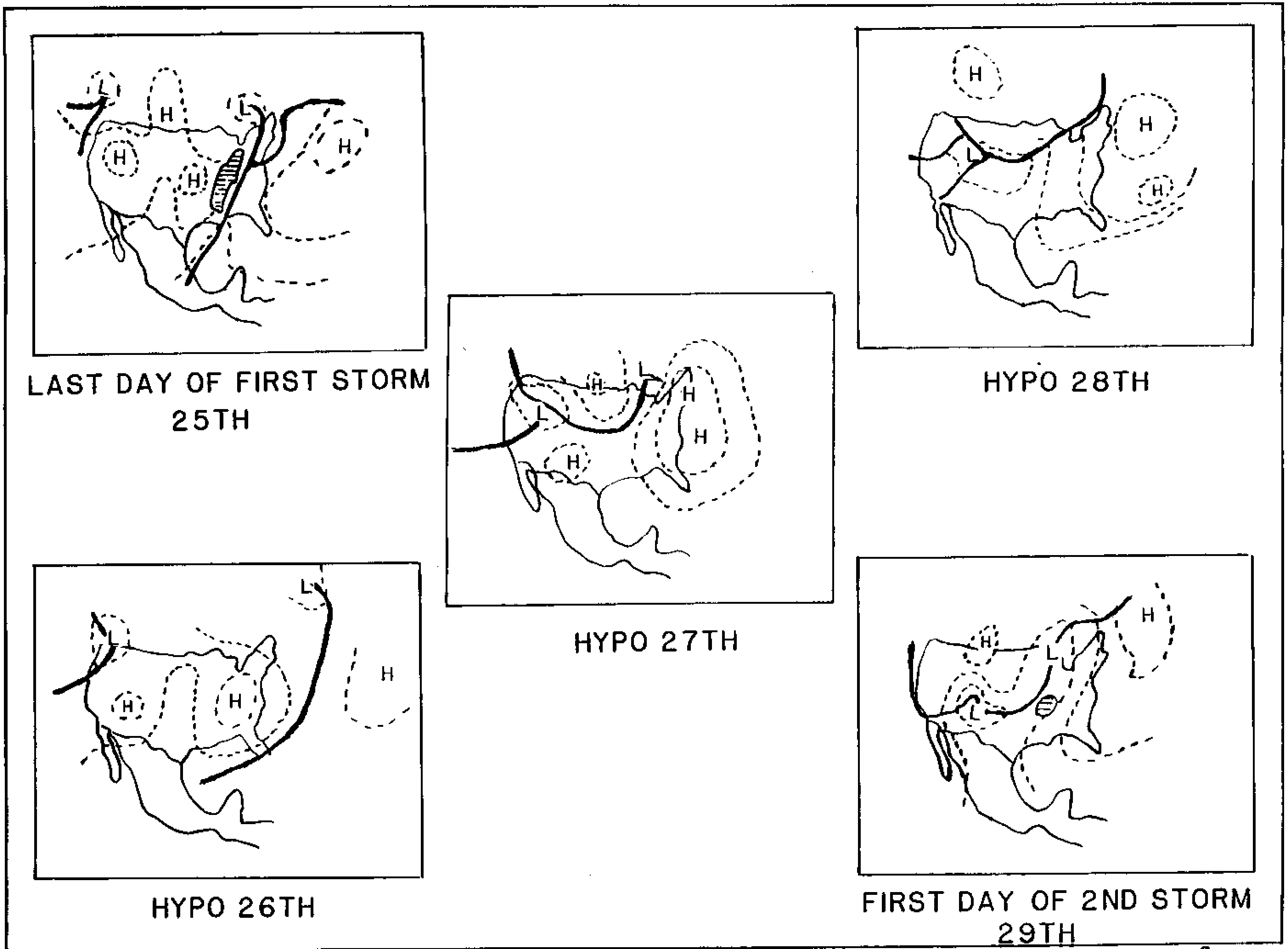

Figure 105.--Hypothetical transition from one major storm event to a second major storm event. Sequence illustrates minimum time interval.

storms in the Tennessee Valley area, this moisture must be persistently transported from quite low latitudes in the Gulf of Mexico. A shorter time interval between major storms would require unrealistic wind speeds, directions of movement, and transformations of highs and lows. Intervals longer than 3 days allow the cold dry continental air to remain over the basin for longer periods before the moisture laden air flow from the south is reestablished.

A 3-day rainless interval preceding both the PMP and TVA maximum 3-day rain has been adopted in this study. The relative rarity of the total rainfall event for PMP vs. TVA precipitation is handled by changing the magnitude of the antecedent rainfall rather than using a varying rainless interval.

7.3.3 Magnitude of Antecedent Storm 3 Days Prior, as Percent of Main Storm

A probable maximum storm is an extremely rare event. It has not been equaled by any historic event. In only a few cases has any storm come close to PMP and then only for a few durations and area sizes. Estimates of rainfall antecedent to PMP must be determined from storms of lesser magnitude. Several approaches were used to determine the appropriate magnitude for the Tennessee Valley.

7.3.3.1 Guidance From Station Rainfall Events. Information about antecedent storms for areas in the smaller end of the size range of interest can be gained from investigation of point or station rainfall data. The data are the rainfall observations taken at the many stations for which the National Weather Service publishes daily rainfall amounts.

Four different procedures were used in developing guidance from station rainfall values; 1) ratios of 9- to 3-day 100-yr rainfall; 2) average ratios of 6-day rain adjacent to or surrounding the maximum annual 3-day rainfalls for 250 stations in eastern Tennessee and western North Carolina; 3) average ratios between the 6-day adjacent rain and the maximum 3-day value within a 9-day storm for rains greater than 4.5 in. in 9 days for four stations, and 4) ratios between the 6-day adjacent rain and 3-day rains greater than 7 in. from 4,000 yr of stochastically generated rainfall values at Bristol, TN.

In the station rainfall studies, two approaches were used. In one, the maximum annual 3-day amount was selected and the largest 6-day amount adjacent to the maximum 3-day amount was determined. The 6 days could be either completely before or after the 3-day period, or it could be partly before or after (fig. 106). In the other, the maximum annual 9-day amount was selected and the maximum 3-day period within the total storm determined.

7.3.3.1.1 Ratio of 9- to 3-day 100-yr rainfall. Rainfall-frequency values for the 100-yr recurrence interval for 2- to 10-day periods are readily available (Miller 1964). Ratios of 9-day 100-yr to 3-day 100-yr values were determined for a grid of points in and surrounding the Tennessee Valley. Isopleths drawn to this grid point data are shown in figure 107. The average ratio for the Valley is slightly over 1.30.

These ratios can only be used as guidance to ratios applicable to the main storm plus antecedent storm sequence and cannot be applied directly. They are slightly higher than would be expected in that sequence for the following reasons:

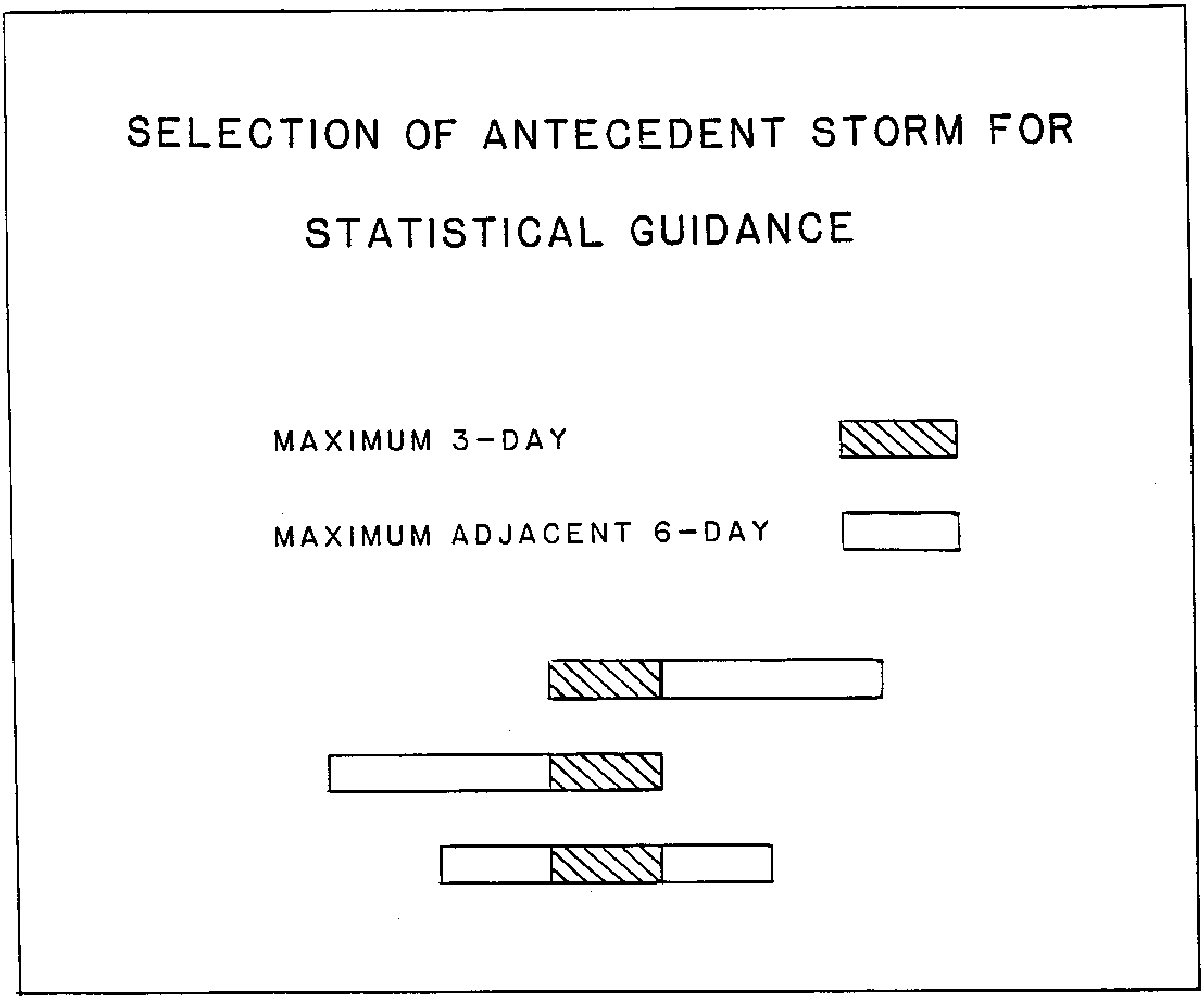

Figure 106.--Illustration of method for selecting maximum 6-day rainfall associated with maximum 3-day amounts. Rain may occur in any one or all of the 9-day period. The 6-day event may be any combination of days before or after providing only that the 9 days are consecutive.

1. The ratio procedure assumes the 3-day 100-yr rain occurs within the 9-day 100-yr rain, while each of the values was obtained from independent data sets. In some cases, individual maximum 3-day and 9-day values are from situations not meteorologically compatible; e.g., the 3-day amount may be from a tropical storm and the 9-day amount from a series of extratropical low pressure systems occurring in spring or winter. Studies for the Ohio River Valley (Miller and Frederick 1972) and the Arkansas-Canadian River Valleys (Frederick 1973) indicate that the 3-day 100-yr rain generally does not occur within the 9-day 100-yr rain.

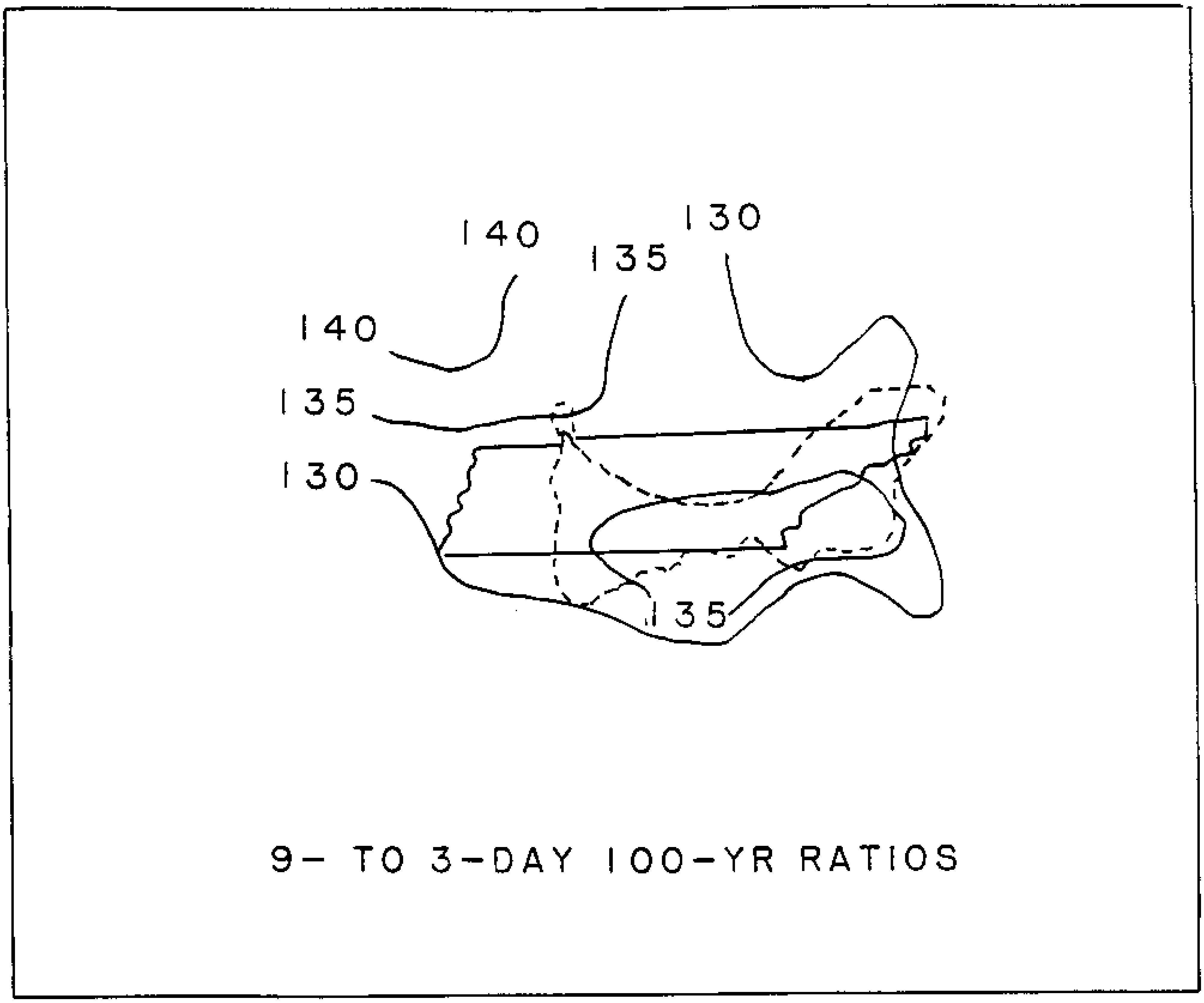

Figure 107.--Ratio of 9-day 100-yr to 3-day 100-yr precipitation values for Tennessee Valley.

2. The difference between 9-day and 3-day values (generally 30-38 percent of the 3-day) can occur in more than 3 of the 6 remaining days.

<u>7.3.3.1.2 6-day rain adjacent to maximum annual 3-day rain.</u> For 250 stations in Tennessee east of 86°W and in North Carolina west of 80°W, 25 yr of data ending in 1973 were available on magnetic tape. For these stations, the maximum annual 3-day rain and the maximum 9-day value including the 3-day maximum were found for each year of record. From this, the 6-day rain adjacent to or surrounding the maximum 3-day rain was determined. The data were grouped according to the magnitude of the 3-day value. Three intervals were selected: Less than 4 in., 4 to 6 in., and greater than 6 in. Figure 108 shows average adjacent rainfall for the 6 days in terms of a percent of the 3-day rainfall. It is evident from this plot, as the magnitude of the 3-day rain increases, the average adjacent storm as a percent of the major storm decreases. For the smallest 3-day rainfall amounts, 0 to 4 in., the average adjacent rain is about 27 percent. When the 3-day rains are in excess of 6 in., the adjacent rain on the average is less than 15 percent of the maximum 3-day value. Maximum observed station rainfalls are less than PMP magnitude, but extrapolation to that magnitude would give lower

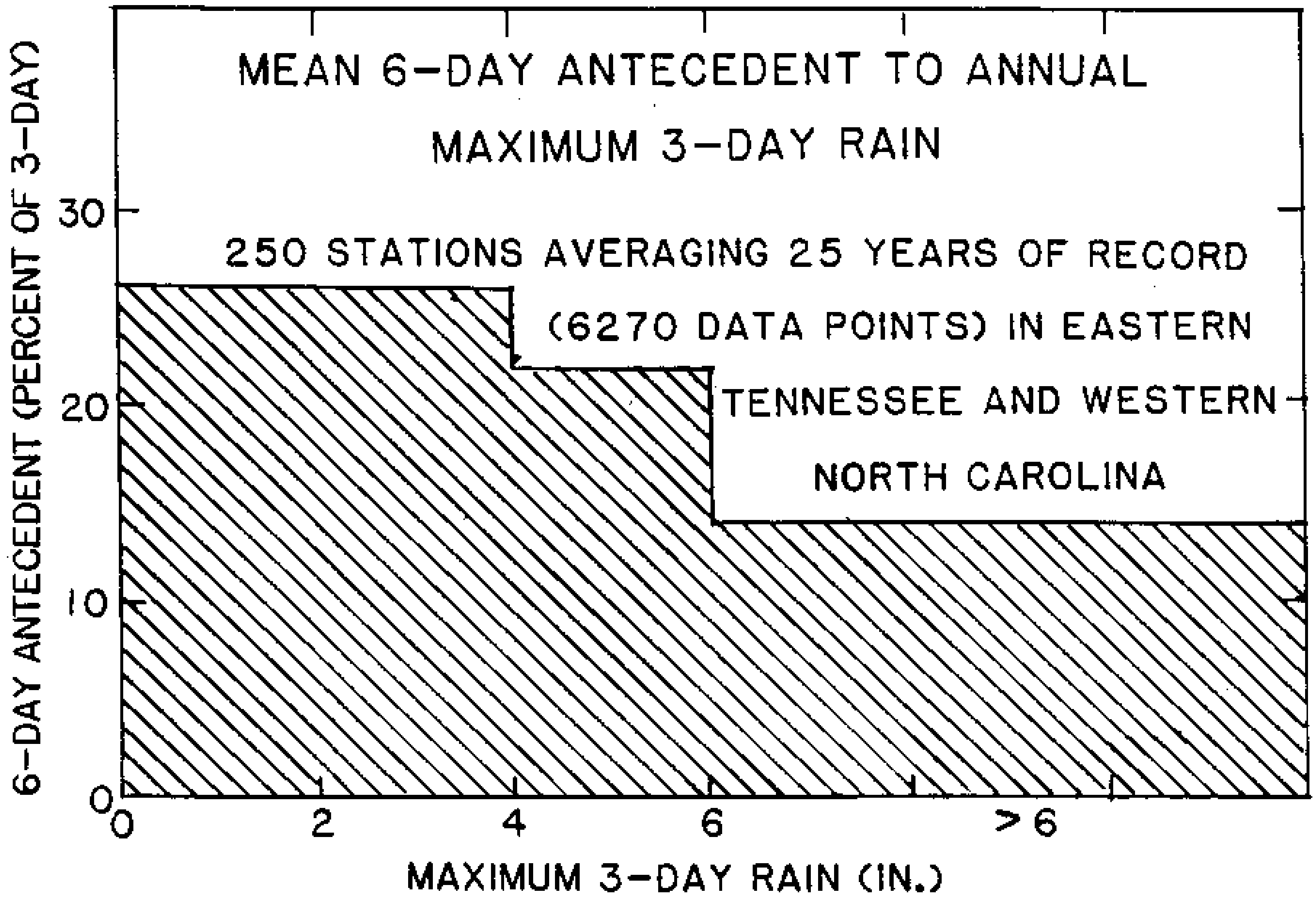

Figure 108.--Average ratio of 6-day rain antecedent to maximum 3-day rains for 250 stations in eastern Tennessee and western North Carolina.

percentages of between 10 to 15 percent. There are several reasons this guidance from maximum 3-day rain and adjacent 6-day rain shows decreasing percentages of antecedent rain in relation to the primary storm.

1. Meteorologically, the trend of decreasing adjacent rain with increasing magnitude of the 3-day storm is realistic. The more intense the first storm, the more unlikely it is to have a following intense storm in a short period of time. Now having set the 3-day PMP (between 33 and 44 in. for stations in this region) it follows, it is more and more unlikely to realize a large antecedent rain as the magnitude of the primary storm increases.

2. The adjacent rain is made up of the sum of the rain for 6 days. These 6-days can all occur (1) before the 3-day maximum rain, (2) after it, or (3) encompass the 3-day maximum rain; e.g., 2 days before it and 4 days after it. If the data selected were restricted to 6 consecutive days, either before or after, some of the resulting antecedent rainfalls would be less.

3. The adjacent rain determined does not conform to the sequence of 3 dry days between the 3-day antecedent storm and the 3-day main storm. We have summed the rain for a 6-day period (or 2 shorter periods broken by the maximum 3 days). Were the data restricted to sequences with 3 dry days, or even used as only

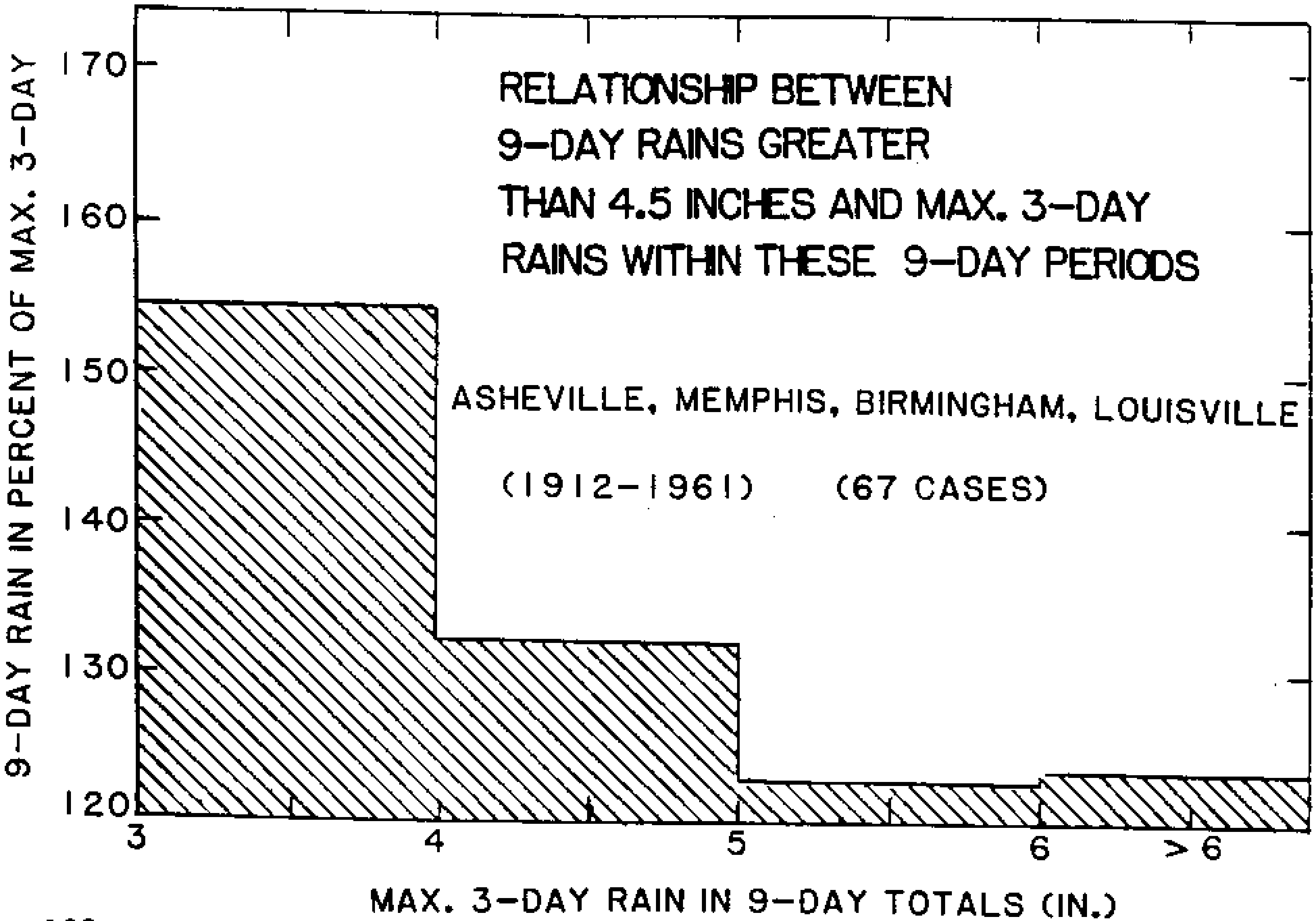

Figure 109.--Relation between 9-day rains, greater than 4.5 in. and maximum 3-day rains within those 9-day periods. Data are for 50-yr period 1912-1961 for Asheville, NC, Memphis, TN, Birmingham, AL and Louisville, KY.

the rain over a 3-day period, with a 3-day gap before or after the 3-day maximum value, the resulting antecedent would be much less. The adjacent rain could just as well have occurred in 3 days, with a 3-day dry interval.

<u>7.3.3.1.3 Station 9-day rains greater than 4.5 in.</u> Maximum 9-day warm season June through October rains, for the period 1912-61 at Asheville, Memphis, Birmingham and Louisville provided additional information to help evaluate antecedent rains. Memphis, TN, and Asheville, NC, are representative of two different topographic settings within the Tennessee Basin. The mountainous east is represented by Asheville and the less rugged western portion of the Tennessee drainage by Memphis, TN. Birmingham, AL and Louisville, KY, provide useful information south and north of the basin, respectively.

During this period, 67 cases of 9-day rains in excess of 4.5 in. were found. The data were summarized by magnitude of the maximum 3-day rain. This relation is illustrated in figure 109 and shows a decrease of the adjoining rain as the magnitude of the maximum 3-day rain increases. This is the same trend that is shown in the data for the 250 stations in eastern Tennessee and western North Carolina. The maximum 3-day rainfall was 12.27 in. The 9- to 3-day ratio for this storm was 1.24. Extrapolation of this or the average ratios to the PMP magnitude would give lower values, slightly less than 20 percent. The 1-percent increase for the 9 cases with 3-day rains greater than 6 in. is not statistically significant.

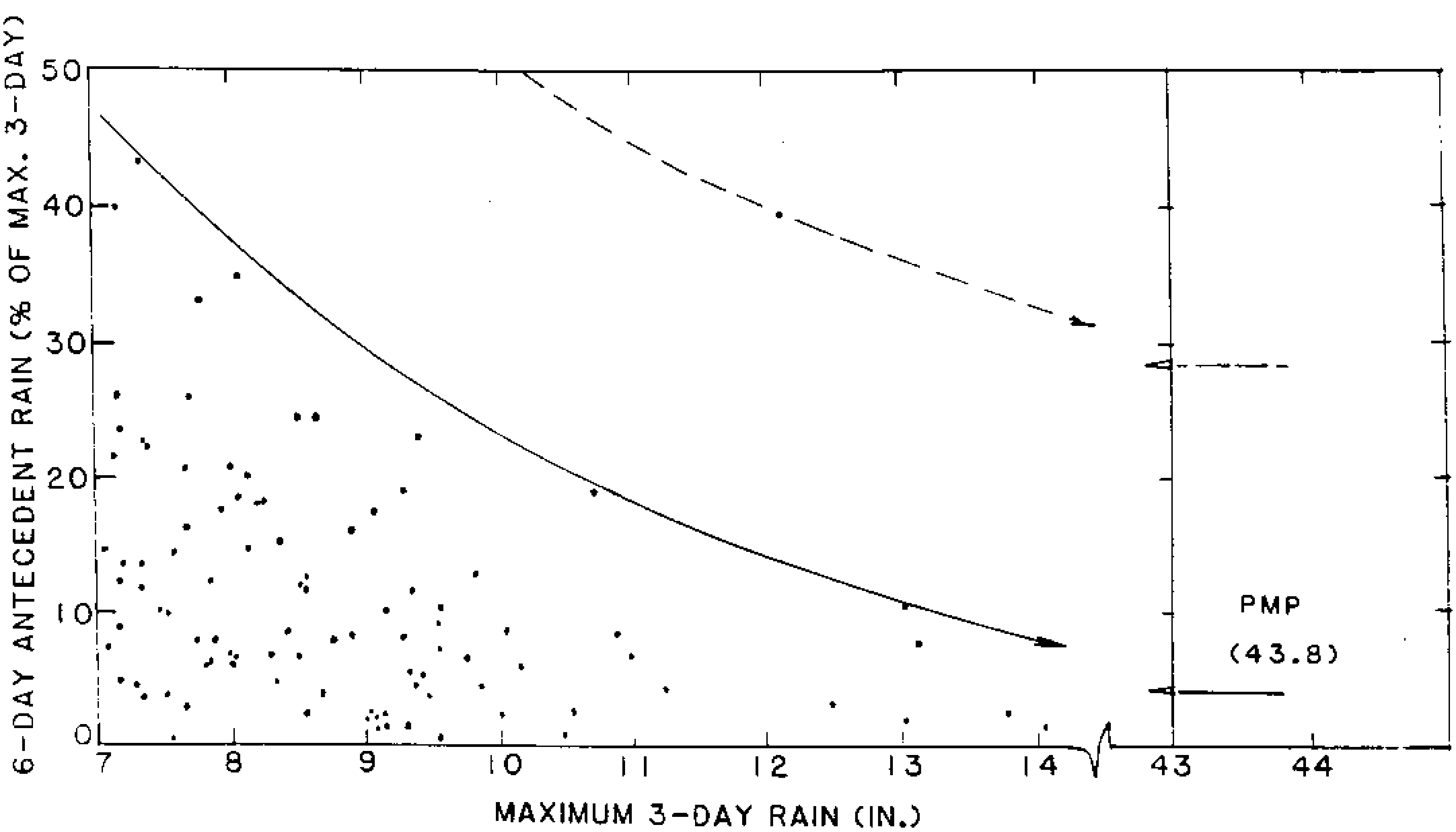

Figure 110.--Relation between statistically generated maximum 3-day rains and 6-day antecedent rainfall based on Bristol, TN data. First-order Markov chain, Kappa 3 distribution and retaining proportion of days above various thresholds among primary criteria for generating statistical series.

The same maximizations are present in this data set as in the previous ones. The adjoining rainfall may come from 2 storms and the 6-day amount is assumed to occur in 3 days. These two factors bias the results toward a higher percentage than can be expected in a large primary storm plus antecedent storm sequence.

7.3.3.1.4 Statistically generated rainfall data. Among the newer techniques of rainfall analysis is the generation of a long series of daily rainfalls that preserve the statistical properties of the initial data sample. This has been done for Bristol, TN to gain additional insight into the question of antecedent precipitation. The basic period of record for the daily rains is for the 25 yr between 1949 and 1973. Very briefly, the technique used a first-order Markov chain to describe the variations between rain days and no rain days. Then rainfall amounts were generated by the Kappa 3 distribution. In all rainfall generation techniques some upper bound is necessary. In this study, an upper bound equivalent to the PMP at this location was used. The calibration scheme applied also preserved the observed mean daily rainfall and the proportion of days with rain exceeding certain threshold values. The maximum daily rainfall generated was a little less than 12 in. or about 4 times the maximum observed. The maximum 3-day rain generated was a little over 14 in. or about 3 times the maximum observed.

For this particular application, forty 100-yr periods of daily rainfalls were generated. From each 100-yr segment, all 3-day rains in excess of 7 in. were selected and the maximum 9-day rain was determined which included the 3-day period. The results of this study are shown in figure 110. A trend line (solid line) is shown that envelops most of the data. This shows a decrease in

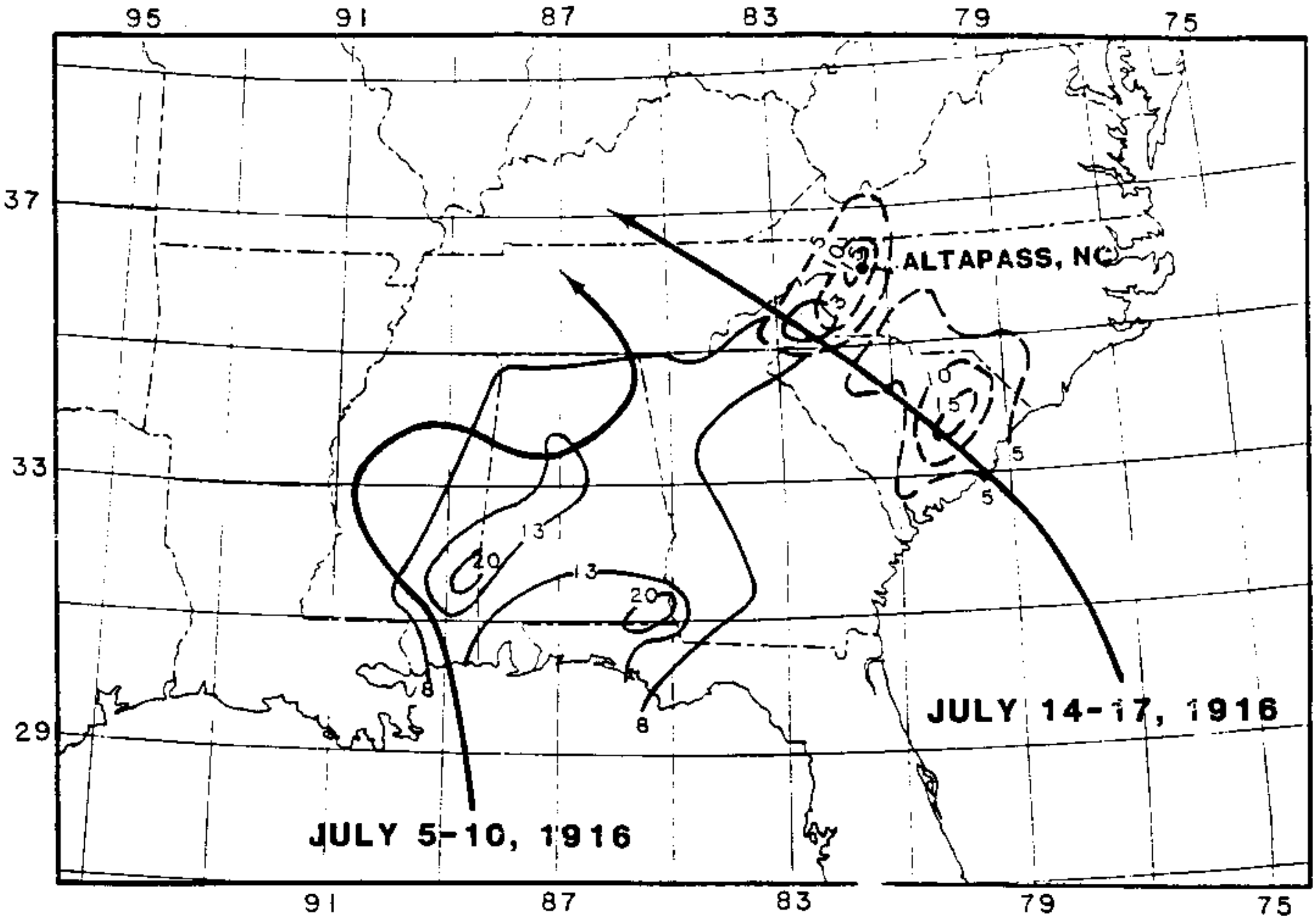

Figure 111.--Isohyetal patterns and storm tracks for storm centered at Altapass, NC, July 14-17, 1916, and the same information for the storm that occurred on July 5-10, 1916, in Alabama, Georgia and the Carolinas.

antecedent rainfall as the magnitude of the 3-day rainfall increases. There is one point which is above this trend line. An enveloping line (dashed) passing through this point with the same curvature and parallel to the trend line would show an antecedent rainfall of less than 30 percent for maximum 3-day rainfall equivalent to the PMP.

7.3.3.2 Guidance From Areal Storm Rainfall Events. "Storm Rainfall" (U.S. Army 1945-) was searched for the cases where "pairs" of heavy rainstorms occurred near the same location. The most important storms were determined and some discussions concerning them are as follows.

7.3.3.2.1 July 1916 storms in North Carolina and Tennessee. One of the more intense storms in the southeastern United States was centered at Altapass, NC on July 14-17, 1916. Figure 111 shows the storm track and isohyetal pattern from this storm, and also the storm track and isohyetal pattern for the storm prior to the Altapass, NC storm. There were two major centers in the July 14-17 storm, one in coastal South Carolina and the other near the South Carolina-North Carolina border. The antecedent storm was centered in coastal Mississippi, Alabama, and northwest Florida. A secondary rainfall center occurred in the mountains of the North Carolina-South Carolina border region as the storm center continued its erratic movement northward and crossed into Tennessee. These two July 1916 rainfall events were both of tropical origin. The first storm was reduced to a tropical depression (dissipation stage) at the time rain fell over North Carolina. The second storm was still a tropical storm when it passed through the mountains of North Carolina. The heavier rainfall in the Carolinas is in each case a combination of the orographic intensification on the slopes of the mountains and the vertical motion associated with the tropical cyclone. The primary storm produced over 23 in. at Altapass during a 3-day period, July 14-17. The 3 days between this and the earlier storm, the 10th, 11th and 12th, was a relatively dry period averaging 0.1 to 0.2 in. per day.

HMR No. 45, figure 5-5, depicted point data from this extreme pair of large area storms nearest the Tennessee Valley. Figure 112 shows these data replotted with the antecedent rainfalls expressed as a percent of the main 3-day rain rather than as magnitude. Figure 112 indicates that as the magnitude of the 3-day rain increases, the antecedent rain, as percent of the major storm, decreases.

The trend is meteorologically realistic. The large antecedent storm utilizes available moisture and ends when drier air involved in the circulation about the storm covers the area. In these large storms, the system is generally moving and both the mechanism and the moisture supply continue a general eastward or northward movement. The larger the storm and the more complete the change to a non-storm situation, the more time is needed to reinstate a moisture supply from the Gulf of Mexico or Atlantic Ocean and to reestablish a meteorological system conducive to heavy precipitation. This trend indicates that a storm with precipitation equal to 30 percent of PMP antecedent to the PMP is conservative.

7.3.3.2.2 May 1943 storms in Oklahoma. In May 1943, two extreme storms occurred in northeastern Oklahoma. Some knowledge can be gained by examination of the rainfall associated with these two storms, but two important facts must be considered. First, the storms occurred outside the season for PMP in the Holston River basin, and second, the storms are not transposable to the watershed. The May 6-12, 1943 rainstorm centered at Warner, OK, was followed by that of May 12-20, 1943 centered at Mounds, OK (fig. 113). These two stations are the centers of the heaviest point precipitation in each storm and are located approximately 50 mi apart. The area of heaviest rainfall over significant areas, (say approximately 2,000 mi^2) was more widely separated, centered about 110 mi apart.

Although the dates for these two storms reflect a nearly continuous period of rainfall, there was a definite dry period of 5 days between the significant rainstorms. If one were to superimpose a maximum 2,000 mi^2 depth from the first storm over that of the second storm, the antecedent rainfall would be 83 percent. If only the 3-day criteria were used the antecedent rainfall would have been 23 percent.

There are two factors to assess in this storm pair. First, the centers for the 2,000-mi^2 area rainfalls were not coincident. They would have to be transposed to have occurred at exactly the same point. This requires an unspecified degree of maximization. The period between the storms was 5 days and reduction of the interval to 3 days would be another maximization. These two storms are of a type which can be transposed to western Tennessee, but is not considered realistic for the eastern part of the Tennessee Valley. Major modifications of the synoptic weather patterns and the sequence of weather events would have to be made to

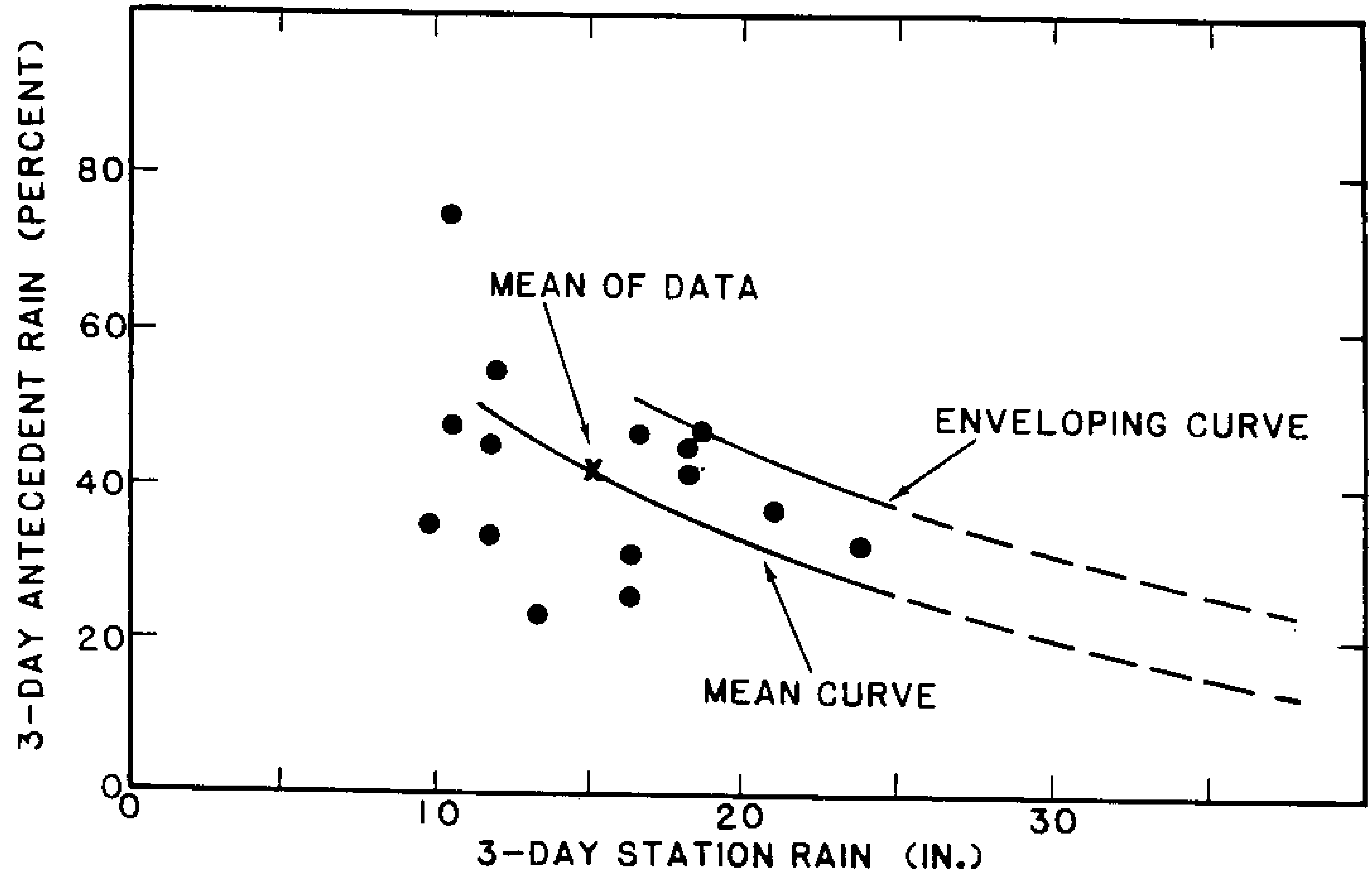

Figure 112.--Station rainfall antecedent to July 14-17, 1916, rainstorm in western North Carolina.

transpose these storms to the eastern part of the Tennessee Valley. Use of these two factors for guidance, therefore, requires judgment in determining how much maximization is involved in each of the steps. Subsequently, a decision would have to be made as to how much maximization is appropriate for the development of the antecedent storm to a PMP storm.

7.3.3.2.3 January 1937 storm in the Mississippi Valley. The record-breaking storm of January 1937 provides some information on long duration rain characteristics over fixed areas. The 3-day rains (U.S Army 1945 -) and 11- to 3-day and 15- to 3-day rain ratios for selected area sizes in this storm are listed in table 24. The 3-day rain values range from 11.0 in. for 500 mi^2 to 9.6 in. for 5,000 mi^2.

In assessing the significance of the ratios in table 24, the magnitude of the 3-day rainfall should be kept in mind. Although large, these values fall considerably short of the magnitude of PMP values of this report for summer rainfall. The resulting ratios, therefore, should be considered as too high for application to summertime 3-day PMP and for 3-day TVA precipitation.

There are two maximizations involved in the use of ratios from this storm. The first is compressing the rainfall in the period beyond the maximum 3 days into a 3-day period since the rain fell almost continuously during the 11 and 15 days. The second is in assuming that the maximum rains for the two durations were coincident in location. Even though these came from the same storm, the area covered by the maximum 3-day rainfall was not coincident with the area covered by the maximum 11- or 15-day interval.

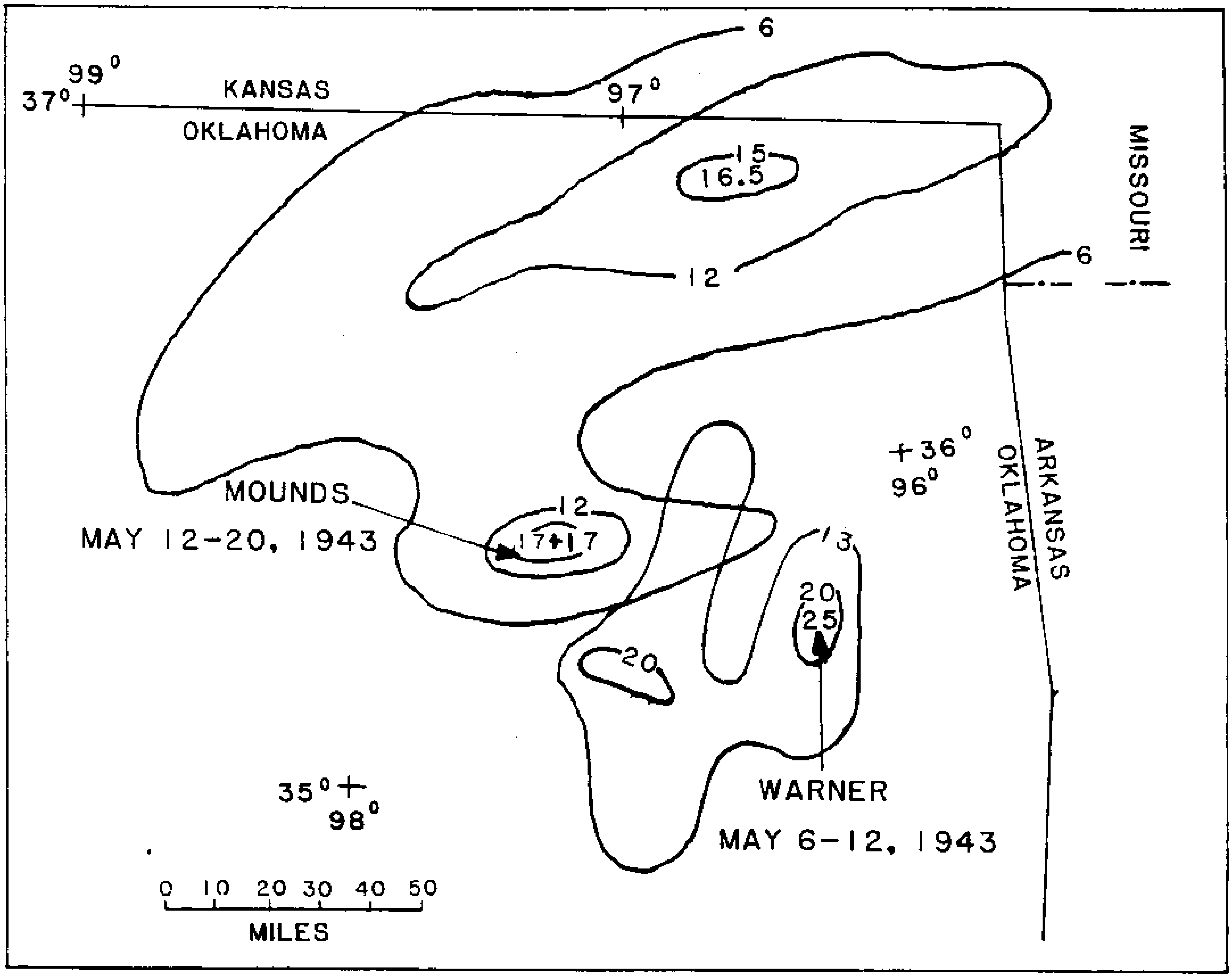

Figure 113.--Isohyetal patterns for May 6-12, 1943 storm centered at Warner, OK, and the May 12-20, 1943 storm centered at Mounds, OK.

Table 24.—Durational rain ratios in January 1937 storm

Area (mi^2)	3-Day Rain (in.)	11- to 3-Day ratio	15- to 3-Day ratio
500	11.0	1.85	1.95
1000	10.7	1.90	1.99
2000	10.3	1.96	2.08
5000	9.6	1.94	2.08

7.3.3.2.4 Guidance from rainfall antecedent to major 2,000-mi^2 area storms. A likely prototype for the PMP storm over the Tennessee River Basin is the storm associated with a remnant of a tropical storm. To understand the rainfall regime prior to major tropical storms, the 23 tropical storms that caused large rainfalls in the last 70 yr in the southeastern and eastern United States were examined. For the period prior to 1955, this information came from National

Hurricane Research Project Report No. 33, "Rainfall Associated with Hurricanes," (Schoener and Molansky, 1956.) Subsequent to 1956, data from "Tropical Cyclones of the North Atlantic" (Neumann et al. 1978, revised 1985) provided material on current tropical storms. The storm sample was expanded to add 11 extratropical storms critical to the determination of PMP for 2,000 mi^2 and 72 hr in the United States east of the 105th meridian to insure all rainfall antecedent to all major storms was considered. It should be emphasized that we are considering all major storms in the eastern United States, many of which could not be transposed to the Tennessee River basin. This is a major maximizing step and may introduce both seasonal and geographic maximization.

The locations of these storms are shown in figure 114. The circles show the location of the storm occurrence and the x's show the location of the largest areal value that occurred prior to or after the storm within 300 mi of the storm location. The numbers next to the storm location are identification numbers given in table 25 where pertinent information on each storm can be found.

1. For each storm the area was delineated within which the maximum 2,000-mi^2 rainfall occurred.

2. The daily rains for all stations in this area, from "Climatological Data for the United States by Sections" (Environmental Data Service 1896-1975) were tabulated. For guidance in determining the rain antecedent to the PMP, data for 6 days preceding and following the storm were also tabulated. The station rainfalls were averaged for each of the days, then totaled for the 6 days following the maximum average total for 3 days.

3. Station averages at the location of the storm were determined. The value used was the larger of the two 6-day amounts.

4. The data from stations within a radius of 300 mi^2 of the storm location were examined to determine similar 6-day maximums. These average depths will differ from the storm values found in "Storm Rainfall" (U.S. Army 1945 -). Complete storm studies rely on comprehensive analysis of all regular reporting stations supplemented by field surveys for additional rainfall information. This type of analysis was not available for preceding or subsequent storms. Since the detailed analysis frequently reveals rainfall centers between regular observing stations, using data from "Storm Rainfall" for the primary storm and from only the regular reporting networks for antecedent storms would artificially reduce the percentage the antecedent is of the major rain. A fairer comparison can be obtained by use of a comparable network for both storms.

   Figure 115 shows the percent that the 6-day total rain preceding or following is of the maximum 3-day total for the

Table 25.—6-day 2,000-mi² rainfall antecedent* to major 3-day storm rainfall in the United States

Storm No.	Date	Location	No. Stns. averaged	Greatest 6-day rainfall (before) (in.)	2,000 mi² rain for max. 3 days				Greatest 6-day rainfall (after) (in.)	Antecedent in % of maximum 3-day rain	Storm type
					7	8	9	Total			
1	8/6-9/40	Miller Island, LA	6	4.15	3.91	9.41	14.09	27.41	.49	15	T
					17	18	19				
2	8/16-21/15	San Augustine, TX	3	2.27	7.05	6.41	5.54	19.00	2.47	13	T
					8	9	10				
3	9/8-10/21	Thrall, TX	3	.31	.17	5.88	12.30	18.35	.54	3	T
					13	14	15				
4	3/10-16/29	Elba, AL	10	.39	205	5.74	9.80	17.59	.11	2	NT
					23	24	25				
5	7/22-27/33	Logansport, LA	5	.69	3.62	10.84	2.71	17.17	.79	5	T
					15	16	17				
6	7/14-17/16	Altapass, NC	6	6.48	7.23	8.90	.37	16.50	2.26	39	T
					25	26	27				
7	9/23-10/3/29	Glenville, GA	3	.18	.99	3.47	11.50	15.96	.87	5	T
					27	28	29				
8	7/27-29/43	Devers, TX	5	.17	4.62	8.07	2.74	15.43	.07	1	T
					6	7	8				
9	7/5-10/16	Bonifay, FL	6	1.59	4.87	3.23	7.33	15.43	3.94	26	T
					27	28	29				
10	8/26-29/45	Hockley, TX	4	.10	1.15	10.64	2.79	14.58	.23	2	T
					21	22	23				
11	6/19-23/72	Zerby, PA	7	1.09	1.31	9.53	3.15	13.99	.62	8	T
					4	5	6				
12	8/31-9/6/35	Easton, MD	6	.28	.93	5.44	7.46	13.83	.53	4	T
					20	21	22				
13	9/17-26/26	Bay Minette, AL	6	.12	7.19	5.93	.10	13.22	.06	1	T
					13	14	15				
14	6/12-16/34	St. Leo, FL	5	.78	2.83	1.14	8.78	12.75	3.48	27	T
					4	5	6				
15	9/3-8/50	Yankeetown, FL	18	1.75	1.69	5.32	5.66	12.67	.55	14	
					27	28	29				
16	6/24-28/54	Pandale, TX	2	.12	.27	8.01	3.89	12.17	0	1	
					28	29	30				
17	6/27-7/1/99	Hearne, TX	4	1.37	4.89	4.26	2.84	11.99	.91	11	NT

Table 25.—6-day 2,000-mi^2 rainfall antecedent* to major 3-day storm rainfall in the United States (Continued)

Storm No.	Date	Location	No. Stns. averaged	Greatest 6-day rainfall (before) (in.)	2,000 mi^2 rain for max. 3 days				Greatest 6-day rainfall (after) (in.)	Antecedent in % of maximum 3-day rain	Storm type
					18	19	20	Total			
18	9/16-20/43	Morgan City, LA	4	3.41	4.78	4.58	2.57	11.93	1.04	29	
					29	30	31				
19	8/28-31/41	Hayward, WI	4	.48	.38	8.71	2.69	11.78	1.48	13	NT
					6/30	7/1	7/2				
20	6/27-7/4/36	Bebe, TX	4	1.90	4.75	5.94	1.05	11.74	3.05	26	
					14	15	16				
21	10/11-18/42	Big Meadow, VA	3	.90	4.19	5.70	1.83	11.72	.07	8	
					17	18	19				
22	5/12-20/43	Mounds, OK	8	.53	3.69	5.11	2.87	11.67	.95	8	NT
					8	9	10				
23	10/7-11/03	Patterson, NJ	10	.05	3.17	7.94	.34	11.45	.31	3	T
					14	15	16				
24	8/12-16/46	Collinsville, IL	9	.92	1.49	5.37	4.30	11.16	.01	8	NT
					9	10	11				
25	5/6-11/43	Warner, OK	10	.74	4.83	4.75	1.25	10.83	1.16	11	NT
					21	22	23				
26	1/5-25/37	McKenzie, TN	2	6.92	5.45	3.42	1.48	10.35	2.51	67	NT
					24	25	26				
27	8/23-26/26	Donaldsonville, LA	5	.46	.77	2.34	7.14	10.25	.92	9	T
					21	22	23				
28	10/19-24/08	Meeker, OK	5	2.82	3.14	3.92	3.13	10.19	0	28	NT
					18	19	20				
29	8/17-20/55	Westfield, MA	13	5.64	1.57	7.98	.49	10.04	.59	56	T
					3	4	5				
30	9/2-6/40	Hallet, OK	4	.44	2.10	5.56	1.91	9.57	.16	5	NT
					10	11	12				
31	8/10-15/55	New Bern, NC	6	.52	.48	2.04	7.05	9.57	4.67	49	T
					1	20	21				
32	7/18-23/09	Beaulieu, MN	5	.36	2.68	5.76	.67	9.11	1.14	12	NT
					18	19	20				
33	8/18-20/69	Tyro, VA	6	.63	.02	.20	8.19	8.41	0	7	T
					21	22	23				
34	7/18-23-09	Ironwood, MI	7	.31	1.60	4.02	2.51	8.13	.08	4	NT

*2,000-mi^2 6-day rainfall used as 3-day antecedent before or after (whichever is larger) the maximum 3-day rainfall. All rainfalls based on reporting stations in Climatological Data.

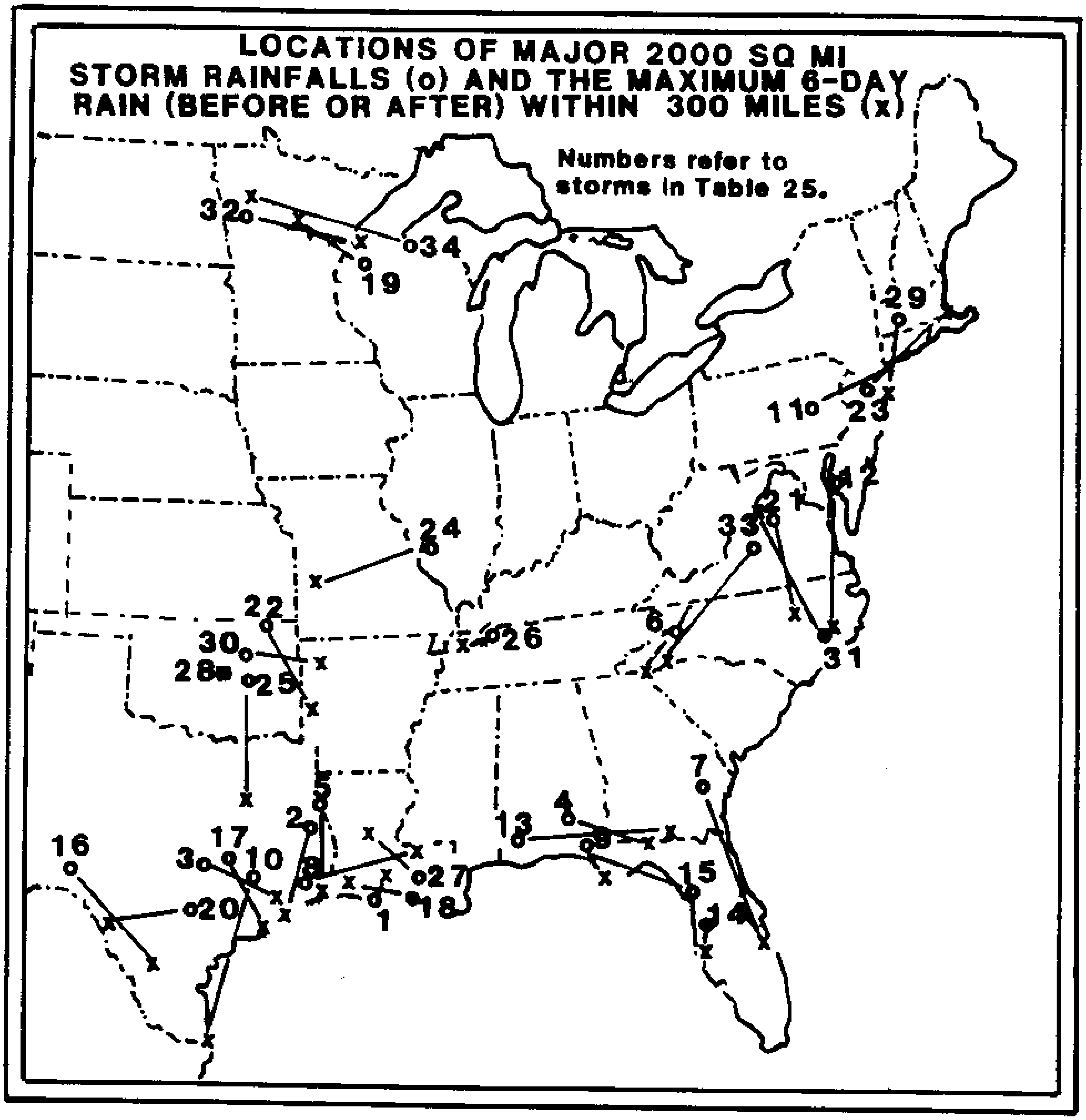

Figure 114.--Location of 34 major 2,000-mi^2 storm rainfalls and the location of the maximum rainfalls within 300 mi before or after major storm.

stations at the storm location. In each case, the 6-day rain used was the greater of the two. The same maximization is inherent in these data as in previous portions of the study. All rain in the 6-day period was included in the 3-day antecedent storm. The envelope of data for the largest storms of records shows a definite decrease in the percent the adjoining 6-day rain is of the 3-day major rain as the 3-day major rain increases in magnitude. The curve in the vicinity of 10 in., is controlled by the storm centered at McKenzie, TN in January 1937 (sect. 7.3.3.2.3). Close support is provided by the Connie and Diane tropical storms of August 1955. These storms control the envelopment of tropical storm data. The July 1916 storm at Altapass, NC (sect. 7.3.3.2.1) controls the

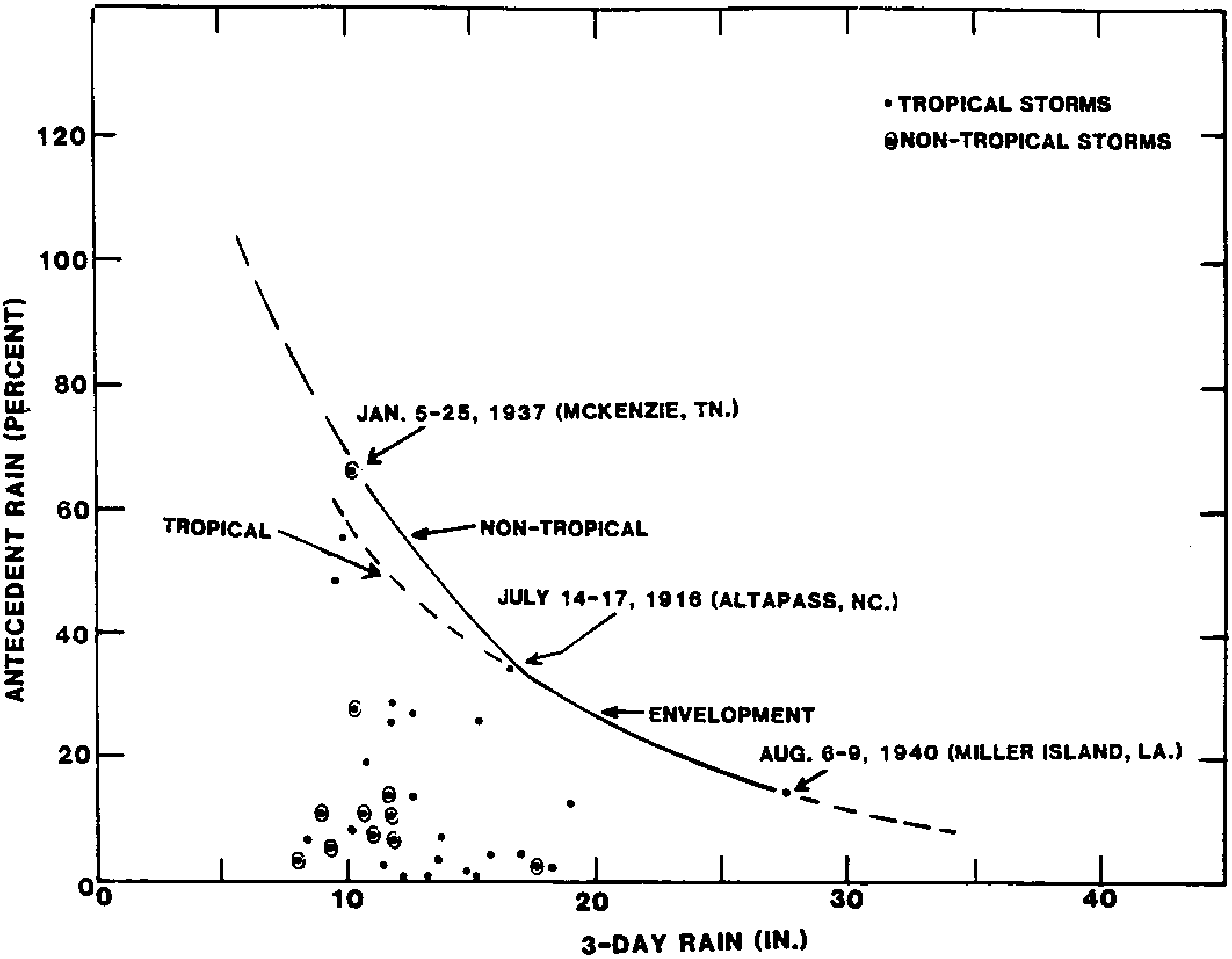

Figure 115.--Ratio of 6-day rain antecedent to 34 major eastern United States storms to major 3-day rainfall amount. Antecedent rainfall determined at location of major storm.

enveloping curves in the range between 16 and 17 in. The curve for the larger 3-day rains is controlled by the coastal storm centered at Miller Island, LA in August 1940.

The next step is to consider rainfall before or after the major storms that occurred any place within a radius of 300 mi of the location of the primary storm. This is a transposition of the rainfall from a secondary storm center to a location of the primary storm. The 300-mi radius is arbitrary but it provides an ample margin for storm transposition. We are considering a region of over 280,000 mi^2. Figure 116 shows an example of this method of storm determination. The primary storm was centered at Collinsville, IL on August 14-16, 1946, storm 24 in table 25. The maximum 3-day rainfall total was 11.16 and the average 6-day rainfall before or after was

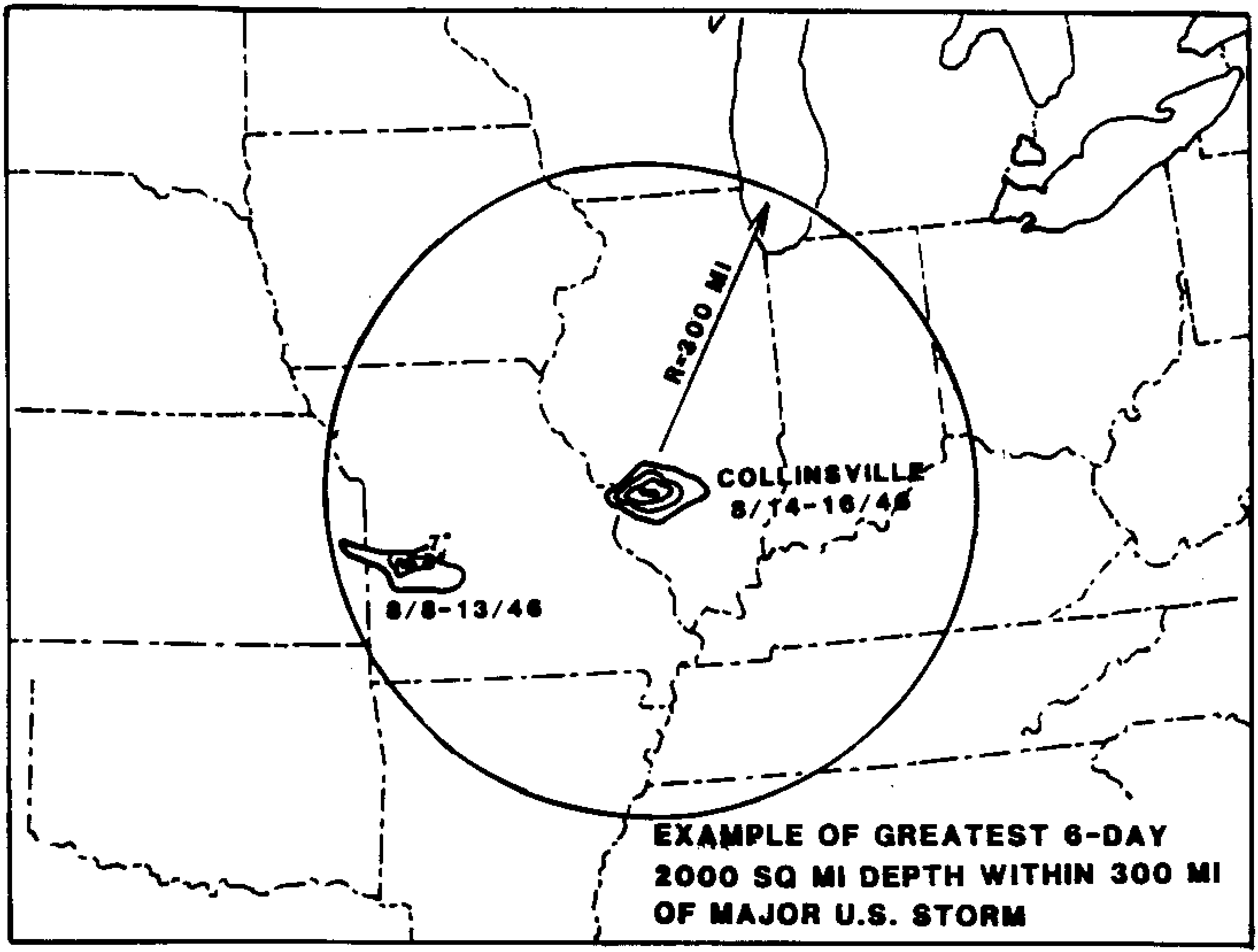

Figure 116.--Example of selection of antecedent storm within 300 mi of major storm location.

0.92 in. at the storm center. A circle of radius of 300 mi includes western Tennessee, and Kentucky, Illinois, nearly all of Indiana, southern Wisconsin, southeastern Iowa, and nearly all of Missouri and northeastern Arkansas. If this 280,000-mi^2 region is considered, a larger storm can be found. This largest rainfall antecedent to the Collinsville storm occurred in western Missouri on August 8-13, 1946, and totaled 7.6 in.

Table 26 provides information on the antecedent rainfall within 300 mi of the major storm rainfall centers previously considered. The same storm identification numbers are used as in table 25. Figure 117 shows the percent that the 6-day total rainfall preceding or following is of the maximum 3-day total. This plot is very similar to the plot shown in figure 115 except that in each case we have considered the maximum rainfall that occurred in any location within 300 mi of the storm center, rather than the rainfall antecedent to the storm at the location of the storm. The curve for the larger 3-day precipitation is again controlled by the July 1916 storm at Altapass, NC and the August 1940 storm centered at Miller Island, LA. At the other end of the curve, approximately

Table 26.—6-day 2,000-mi^2 rainfall within 300 mi antecedent to major storm rainfall in the United States

Storm No. 1	Greatest 6-day 2,000-mi^2 Depth Within 300 mi (in.)	Date of Greatest 6-day Rainfall	No. Stations Used for 6-day Avg. Depth	Location of Greatest 2,000-mi^2 6-day Rainfall (Lat.°N)	(Long.°W)	Antecedent in % of Maximum 3-day Rain
1	5.9	8/1-6/40	5	30°13'	92°01'	22
2	5.1	8/11-6-15	3	29°18'	94°50'	27
3	3.1	9/2-7/21	3	29°21'	95°01'	17
4	3.6	3/16-21/29	4	30°37'	83°55'	20
5	5.9	7/17-22/33	4	29°52'	93°56'	34
6	9.8	7/9-14/16	5	35°03'	83°12'	60
7	10.1	9/19-24/29	4	27°25'	80°19'	63
8	2.4	7/21-26/43	3	30°41'	90°44'	16
9	5.6	6/30-7/5/16	3	29°44'	84°59'	36
10	5.2	8/21-26/45	3	26°04'	97°12'	36
11	8.4	6/15-20/72	11	41°12'	73°12'	60
12	4.0	9/7-12/35	3	38°46'	76°04'	29
13	2.6	9/14-19/26	3	30°52'	83°20'	20
14	5.6	6/8-13/34	3	27°58'	82°32'	44
15	14.2	8/29-9/3/50	5	30°10'	85°40'	112
16	4.4	6/21-26/54	3	27°52'	98°37'	36
17	4.3	7/1-6/99	5	29°02'	95°48'	36
18	6.8	9/12-17/43	9	30°00'	92°47'	57
19	2.6	8/23-28/41	5	47°13'	93°36'	22
20	8.0	6/24-29/36	4	28°43'	100°30'	67
21	6.3	10/8-13/42	6	35°23'	78°00'	54
22	7.0	5/11-16/43	6	35°00'	94°00'	60
23	2.2	10/11-16/03	9	41°53'	70°55'	19
24	7.6	8/8-13/46	9	38°12'	94°02'	68
25	6.2	5/3-8/43	4	32°20'	96°10'	57
26	8.7	1/15-20/37	4	36°16'	88°43'	83
27	2.8	8/27-9/1/26	3	31°19'	92°33'	28
28	5.8	10/15-20/08	3	35°30'	96°54'	57
29	9.5	8/12-17/55	20	40°48'	73°48'	94
30	1.7	8/28-9/2/40	9	36°06'	94°12'	18
31	11.9	8/13-18/55	6	38°31'	78°26'	124
32	1.9	7/22-27/09	4	46°42'	92°01'	21
33	3.6	8/21-26/29	8	35°16'	82°42'	42
34	5.2	7/15-20/09	4	47°34'	95°46'	64

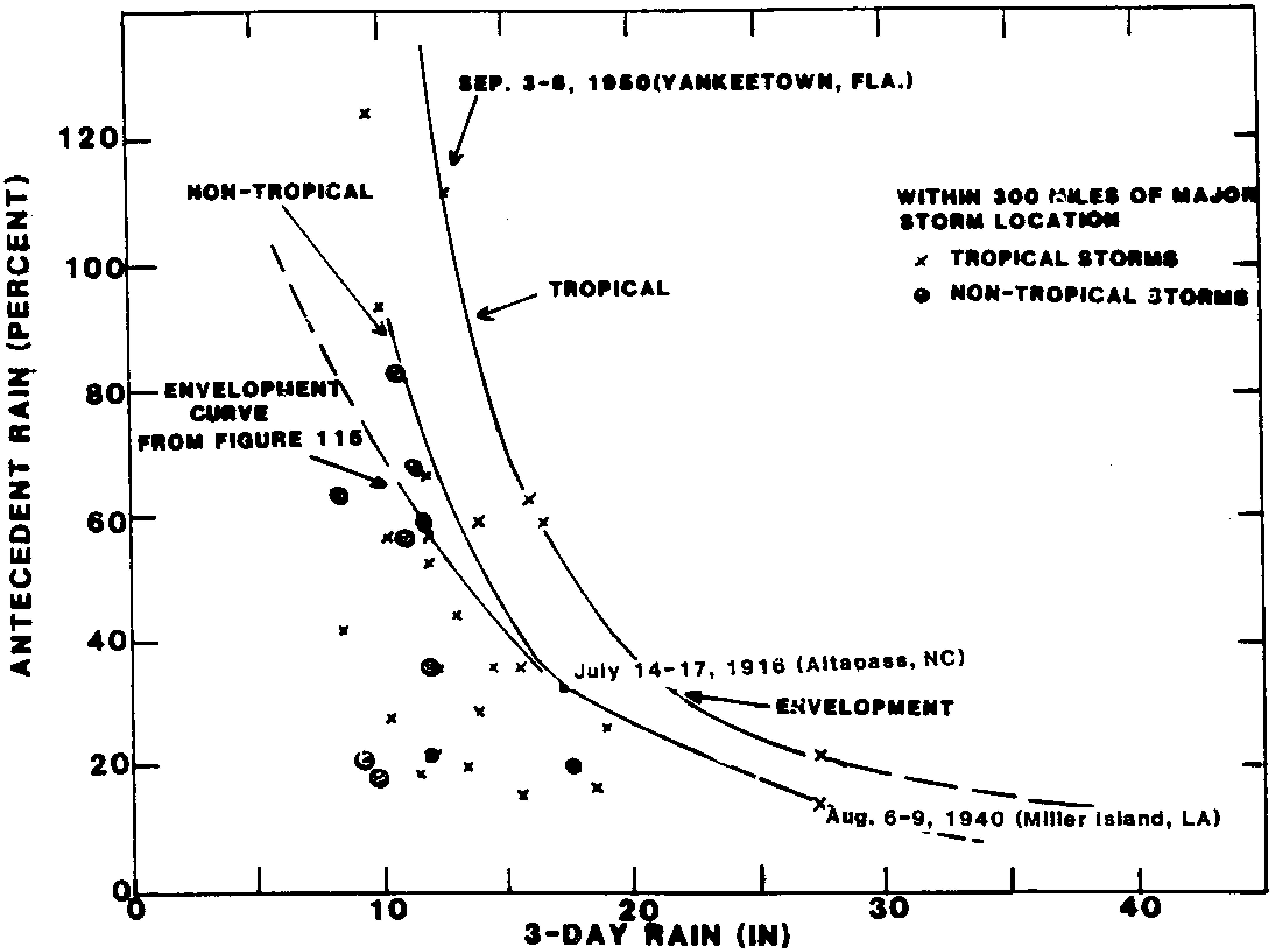

Figure 117.--Ratio of maximum 6-day rain within 300 mi antecedent to 34 major eastern United States storms.

12 in., the curve is controlled by the September 3-8, 1950 storm at Yankeetown, FL. This very high percentage results from an earlier tropical storm, hurricane Baker, that made a landfall near Pensacola, FL on August 30, 1950.

The curve from the envelopment of the antecedent storm at the location of the major storm (fig. 115) is also shown on figure 117. Though the envelopment curve for storms within a radius of 300 mi is moved upward, increasing percentages with the same maximum 3-day rainfall, the same trend of decreasing antecedent rainfall percentages with increasing 3-day rain totals is evident, as in the earlier curves. The differences between the envelopment of antecedent rainfall within 300 mi and of the storm location is greatest at the smaller magnitudes. The two curves tend to converge for the larger storms. Although this study was done for 2,000-mi^2 basins, it applies to basin areas up to 3,000 mi^2 as well.

7.3.4 Magnitude of Antecedent Storm Five Days Prior as Percent of Main Storm

For several of the data sets analyzed previously for the 3-day dry period, an analysis was also conducted based on a 5-day dry period. The purpose of these studies was to determine if storm experience indicated a significant difference in antecedent rainfall magnitude for a longer dry interval. In each of the data sets considered, the 8 days adjoining or surrounding the maximum 3-day period were determined.

7.3.4.1 Ratio of 10- and 11-day 100-yr to 3-day 100-yr Rainfall. The analysis (fig. 107) of 9-day to 3-day 100-yr ratio was based on computations for 16 points in and surrounding the Tennessee River drainage. The average 9- to 3-day ratio was 1.33. Miller (1964) also provides charts for determining 10-day 100-yr rainfall. The average ratio for the same 16 points between 10- and 3-day amounts at the 100-yr recurrence interval is 1.37. Although 11-day amounts are not provided and cannot be determined with exactness, a reasonable approximation can be obtained by extrapolation of the durational diagram from Weather Bureau Technical Paper No. 49 (Miller 1964). These estimated values would permit computation of an average 11- to 3-day ratio (3-day main storm, 5 dry days and 3-day antecedent storm). This estimated average ratio is 1.42.

The 10- and 11- to 3-day ratios are slightly larger than the 9- to 3-day ratio. It would indicate that adding 2 additional "dry" days does not significantly increase the antecedent storm. This procedure would add an additional 9 percent to the ratio developed from 9- to 3-day ratio values. It must be remembered that these ratios also include the maximizations of; 1) an independent data series; 2) no dry days required in the adjacent rainfall, and 3) that the 3-day 100-yr does not necessarily occur within the 10- or 11-day, 100-yr period.

7.3.4.2 Eight-Day Rain Adjacent to Maximum Annual 3-Day Rain. Rainfall for 250 stations in eastern Tennessee and western North Carolina used in the previous section for a 3-day dry interval was reexamined. The same procedure was used as for the 6-day adjoining rain except now 8-day rainfall adjoining or surrounding the annual maximum 3-day rain was determined. The results categorized as before are shown in figure 118. In contrast with data for the 6-day adjacent rain (fig. 108), we see a relatively large increase in the percent the adjacent rain is of the maximum 3-day rain for the smaller rains -- nearly 60 percent for 3-day rain up to 4 in. The antecedent rainfall again decreases as the magnitude of the maximum 3-day rain increases and is 34 percent for the 3-day amounts greater than 6 in. As with the similar study for 6-day antecedent rain, extrapolation to PMP magnitude would indicate smaller ratios. The extrapolation would give between 25 and 30 percent.

The maximization of selecting the maximum 8 days around the 3-day storm and assuming that all the rain is compressed into a 3-day period with 5 intervening dry days apply to this data. The compression of the rain from 8 days into a 3-day storm and a 5-day dry period is a greater maximization than the similar compression for the 6-day adjacent rain. This is because we are assuming all the rain that fell in the 5 intervening days, rather than the 3 days, fell within the 3-day storm.

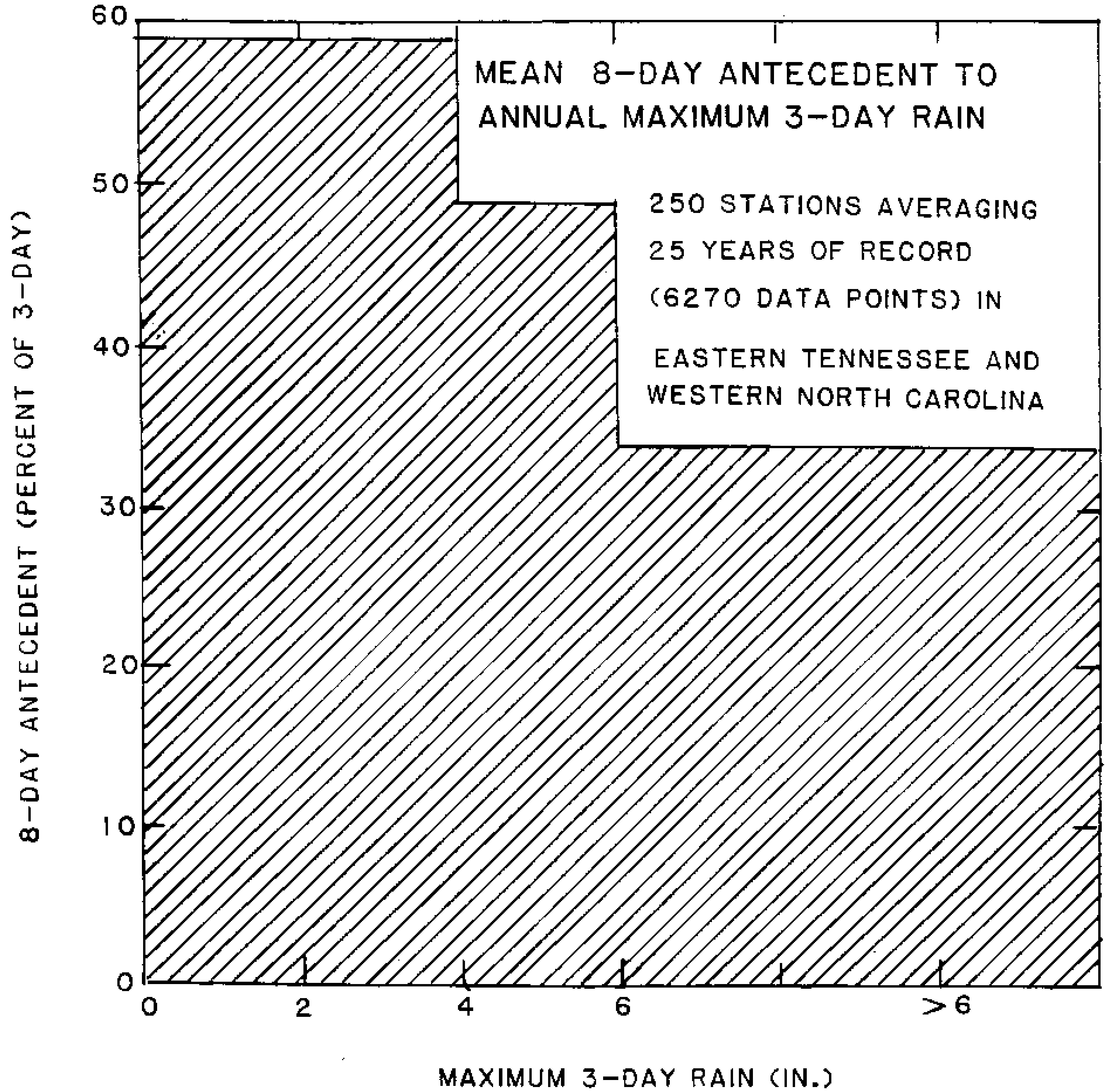

Figure 118.--Average ratio of 8-day rain adjacent to maximum 3-day rains for 250 stations in eastern Tennessee and western North Carolina.

7.3.4.3 Station 10- and 11-day Rains of Greater Than 5 and 5.5 in. Data for Memphis, TN; Asheville, NC; Birmingham, AL; and Louisville, KY were examined for the months of June to October for the period 1912-61. In this 50-yr period all 10-day rain greater than 5 in., and 11-day rains greater than 5.5 in., were selected. There were 58 and 43 cases, respectively. The analysis procedure was the same as that used for the 67 maximum 9-day amounts, and the results were similar. As the magnitude of the 3-day rain increases, the percentage of the adjacent rain was of the maximum 3-day rain decreases. For the 10-day amounts the percentage decreases from 68 to 25 percent (fig. 119), and for the 11-day amounts from 88 to 30 percent (fig. 120). These percentages are only slightly higher than for the 9-day duration (fig. 109). The results of this data also indicate only a slight increase in the magnitude of the antecedent storm as the dry interval increases from 3 to 5 days. The maximum observed 3-day rain was 12.27 in. The 10- and 11- to 3-day ratio for this storm was 1.26 and 1.31 percent, respectively. Extrapolation of the ratio from this storm, or the trend of average ratios to the PMP magnitude, would indicate ratios of about 120 to 125 percent.

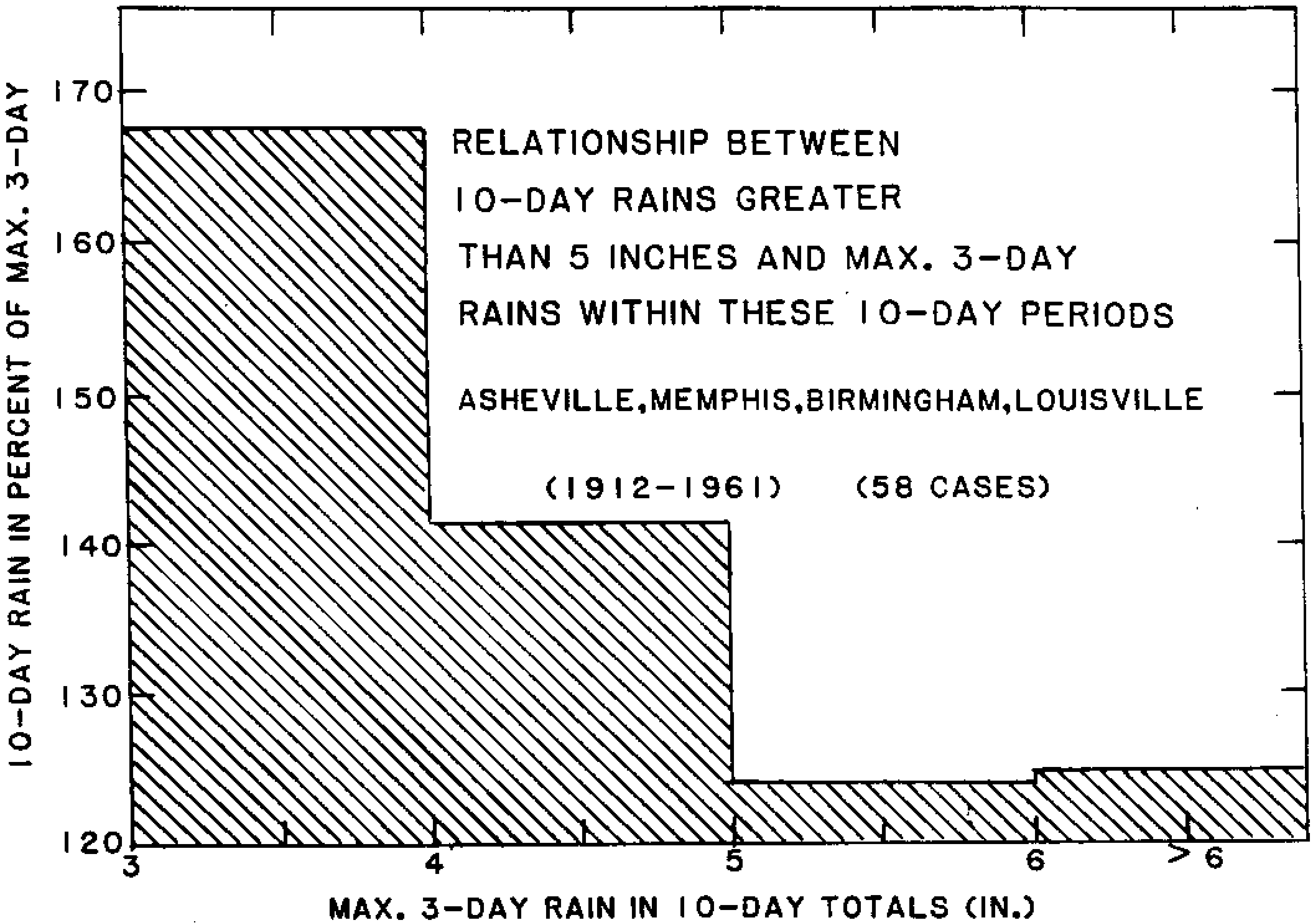

Figure 119.--Relation between 10-day rains, greater than 5 in. and maximum 3-day rains within 10-day periods. Data are for 50-yr period 1912-61 for Asheville, NC; Memphis, TN; Birmingham, AL; and Louisville, KY.

7.3.5 Tennessee Valley Authority Antecedent Rainfall Study

A separate study of antecedent rainfall associated with flood situations in the Tennessee River watershed was done by the Tennessee Valley Authority (TVA) (Newton and Lee 1969). The study was confined to the 41,900-mi^2 Tennessee River watershed. The data evaluated consisted of rainstorms which produced the ten largest floods of record at 47-gaged watersheds. The largest flood was defined by its peak discharge. The watersheds studied were selected from those having long stream gaging records with particular interest in areas from 100 to 3,000 mi^2 where 3-day storm events are likely to control. Within time and data limitations the watersheds were selected to define possible variations with watershed area and geographic location. Drainage area varied from 13 to 2,557 mi^2 with 28 of the 47 investigated being in the 100- to 1,000-mi^2 range.

The basin rainfall which produced a flood and the antecedent rainfall were estimated initially by taking an unweighted average of a selected sample of rain gages located within or near the watershed. When expanding the initial study, Thiessen weighting of all pertinent precipitation data was used to estimate basin rainfall for all added storms. At the same time a selected number of the original storm estimates were reevaluated using all precipitation data and

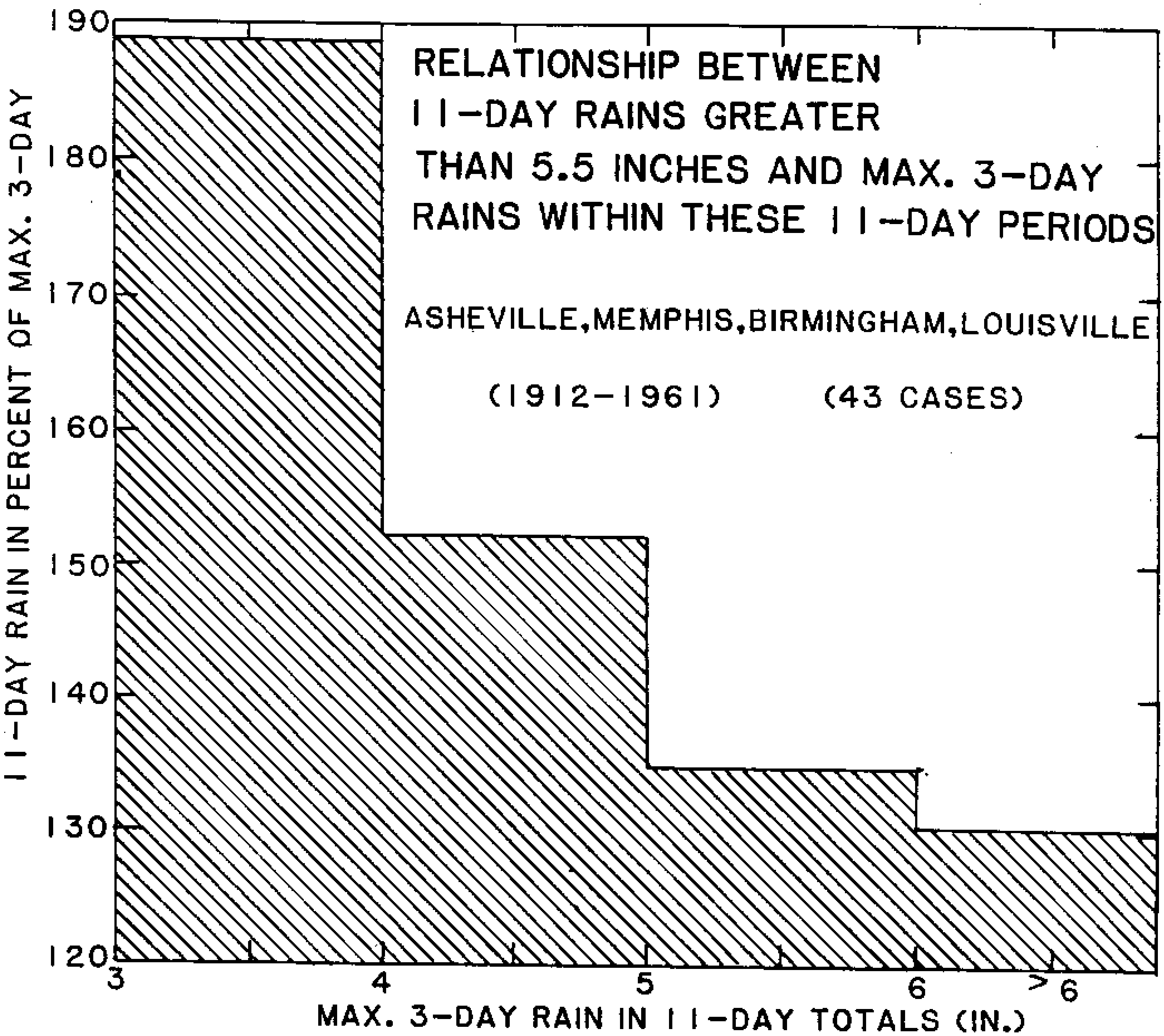

Figure 120.—Relation between 11-day rains, greater than 5.5 in. and maximum 3-day rains within those 11-day periods. Data are for 50-yr periods 1912-61 for Asheville, NC; Memphis, TN; Birmingham, AL, and Louisville, KY.

Thiessen weights. Rainfall for 160 of the 459 floods analyzed was computed using Thiessen weights. Although Thiessen weighted estimates of basin rainfall differed somewhat from the unweighted average estimates, the differences were small and did not affect significantly the results for the purposes of this study.

Storm events were divided into three categories; (1) storms of 3 or less days duration with no antecedent rainfall; (2) storms of 6- to 10-days duration with no distinct break, and (3) storms of 3 or less days duration with a distinct period and an antecedent storm. Figure 121 shows a typical example of a short storm with a distinct antecedent storm. Those events with distinct antecedent storms were analyzed to determine the average length of dry interval between

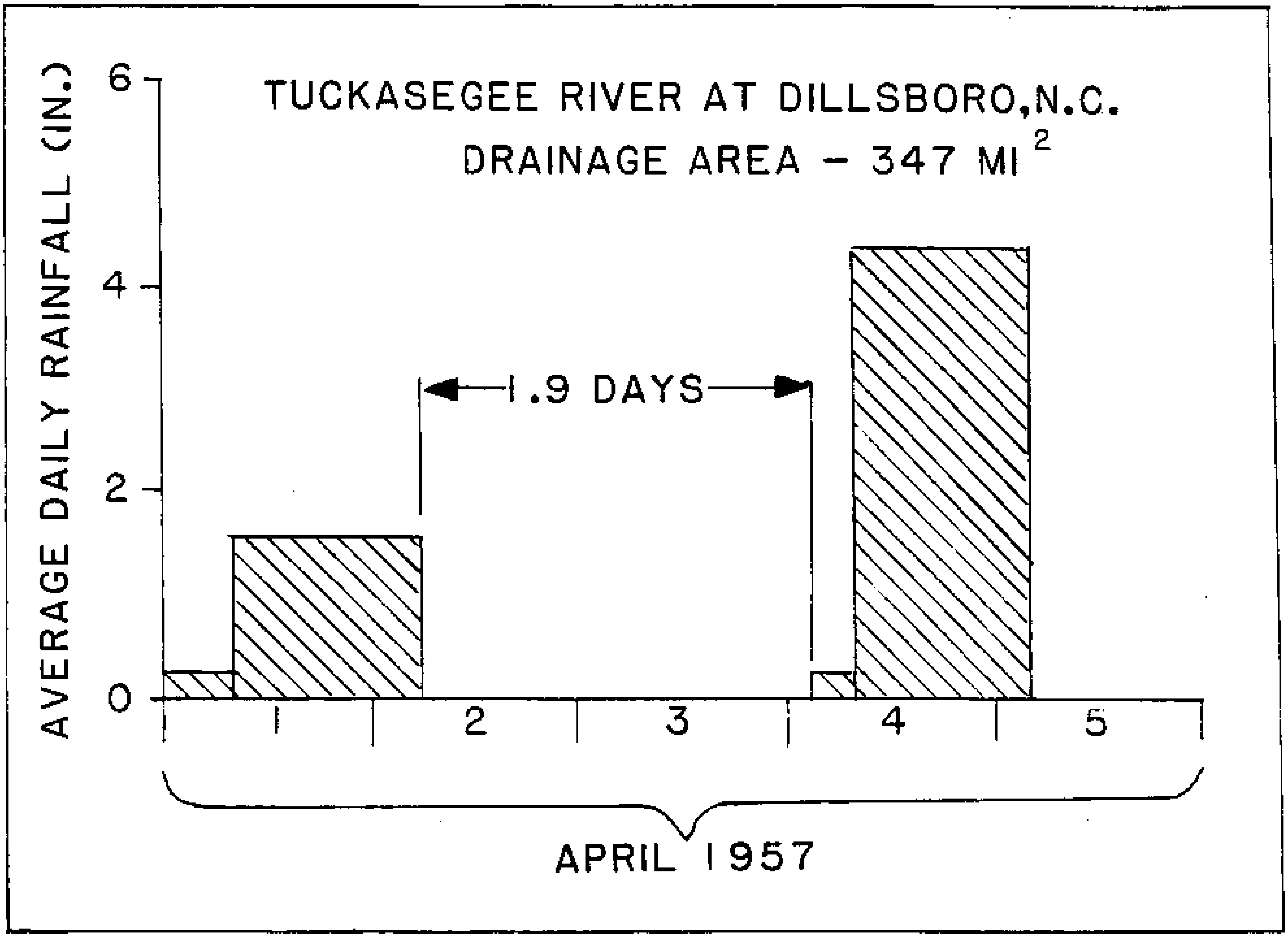

Figure 121.-- Example of storm with antecedent rain.

storms and amount of antecedent rainfall expressed as a percentage of the main storm rainfall.

Tables 27 and 28 summarize the data for the 47 watersheds. Table 27 lists data for all watersheds west of the Appalachian Divide and table 28 for those to the east. This breakdown was made because of the marked difference in the season of maximum flood occurrences. In the "eastern" basins, 48 percent of all the floods and 70 percent of the highest two floods occurred in the "summer" months of May through October. In the "western" section, only 10 percent of the floods studied occurred in the summer.

In the 22 "eastern" watersheds, 73 percent of the floods were produced by storms with antecedent rainfall and an average dry interval of 3.0 days. The median antecedent rainfall was 29.6 percent of the main storm. In the 25 "western" watersheds 77 percent of the floods were produced by storms with antecedent rainfall. The average dry interval between storms was 2.8 days, and the median antecedent rainfall was 24.4 percent of the main storm.

Table 29 shows the results when the data are stratified by season and by flood and storm magnitude. The seasonal and magnitude stratification of data shows that there is some reduction in antecedent storm rainfall for the larger floods and for the summer floods when antecedent rainfall is expressed as a percentage of the main storm.

Table 27. Antecedent storm data, western watersheds

Location of Watershed	Drainage area mi^2	Years of record	Number of floods studied	Percent in Each Case: W/out ante. rain	Percent in Each Case: No break	Percent in Each Case: With ante. rain	Antecedent Storm: Average dry interv. days	Antecedent Storm: Median depth, percent*
North Potato Cr. nr Ducktown, TN	13	33	9	22	11	67	3.7	8.4
Chambers Cr. opposite Kendrick, MS	21.1	20	9	11	11	78	2.9	25.0
Chestuee Cr. at Zion Hill, TN	37.8	18	10	0	20	80	2.7	17.4
Duck River below Manchester, TN	107	33	8	0	25	75	2.4	18.1
Sewee Cr. nr Decatur, TN	117	33	10	0	20	80	3.1	17.6
Limestone Cr. nr Athens, AL	119	28	10	10	10	80	2.6	27.7
MF Holston River at Sevenmile Ford, VA	132	26	9	0	22	78	2.4	50.2
Toccoa River nr Dial, GA	177	55	10	20	10	70	3.7	5.1
Piney River at Vernon, TN	193	42	10	10	30	60	2.7	48.8
Little River nr Maryville, TN	269	17	9	0	22	78	2.8	28.5
Powell River nr Jonesville, VA	319	36	10	10	0	90	2.4	23.4
Flint River nr Chase, AL	342	37	10	20	10	70	2.6	29.1
Shoal Creek at Iron City, TN	348	42	9	11	0	89	2.6	42.1
Sequatchie River at Whitwell, TN	384	47	9	0	22	78	2.7	10.6
Duck River nr Shelbyville, TN	481	33	10	10	20	70	2.9	30.5
Clinch River at Cleveland, VA	528	47	10	0	0	100	3.0	38.3
NF Holston River nr Gate City, VA	672	36	10	10	10	80	2.6	15.6
Powell River nr Arthur, TN	685	48	10	10	0	90	2.4	20.9
Emory River at Oakdale, TN	764	40	10	0	20	80	3.7	18.8
Nolichucky River at Embreeville, TN	805	47	10	0	20	80	3.0	32.6
Elk River above Fayetteville, TN	827	33	10	0	30	70	3.3	14.0
Duck River at Columbia, TN	1208	47	10	0	30	70	2.2	20.5
Clinch River above Tazewell, TN	1474	48	10	10	0	90	2.2	31.3
Elk River nr Prospect, TN	1784	49	10	0	40	60	2.7	12.3
Duck River above Hurricane Mills, TN	2557	42	10	0	40	60	2.9	23.7

*Percent of principal storm

Ante. = Antecedent
Interv. = Interval
W/out = Without

Table 28. Antecedent storm data, eastern watersheds

Location of Watershed	Drainage area mi^2	Years of record	Number of floods studied	Percent in Each Case: W/out ante. rain	No break	With ante. rain	Antecedent Storm: Average dry interv. days	Median depth, percent*
Allen Creek nr Hazelwood, NC	14.4	18	10	10	10	80	3.6	26.1
WF Pigeon River above Lake Logan, NC	27.6	13	10	10	30	60	2.6	34.0
Davidson River nr Brevard, NC	40.4	47	10	30	0	70	2.9	25.7
Clear Creek nr Hendersonville, NC	42.2	10	10	0	10	90	3.1	43.3
Scott Creek above Sylva, NC	50.7	26	9	11	22	67	2.7	26.5
South Toe River at Newdale, NC	60.8	18	9	11	11	78	4.4	21.9
Cane Creek at Fletcher, NC	63.1	16	10	20	0	80	2.8	37.3
Jonathan Creek nr Cove Creek, NC	65.3	37	10	10	20	70	3.3	15.7
Mills River nr Mills River, NC	66.7	33	10	10	20	70	3.1	30.5
French Broad River at Rosman, NC	67.9	29	10	10	10	80	3.2	29.0
Hominy Creek at Candler, NC	79.8	25	10	30	0	70	2.7	27.6
Watauga River nr Sugar Grove, NC	90.8	28	10	20	10	70	2.9	43.9
North Toe River at Altapass, NC	104	24	9	0	0	100	3.0	40.2
Mud Creek at Naples, NC	109	17	10	10	0	90	3.2	45.0
Big Laurel Creek nr Stackhouse, NC	126	33	10	20	10	70	3.4	17.0
Swannanoa River at Biltmore, NC	130	33	10	20	20	60	3.5	45.3
Pigeon River at Canton, NC	133	39	10	30	10	60	2.3	39.4
Cane River nr Sioux, NC	157	33	10	10	10	80	3.5	23.7
Ivy River nr Marshall, NC	158	33	10	10	10	80	2.8	23.3
Tuckasegee River at Dillsboro, NC	347	39	10	10	30	60	2.1	19.7
Pigeon River nr Hepco, NC	350	40	10	10	20	70	3.2	8.9
French Broad River at Asheville, NC	945	72	10	10	30	60	2.6	26.6

*Percent of principal storm

Ante. = Antecedent
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W/out = Without

Table 28. Antecedent storm data, eastern watersheds

Location of Watershed	Drainage area mi^2	Years of record	Number of floods studied	Percent in Each Case: W/out ante. rain	Percent in Each Case: No break	Percent in Each Case: With ante. rain	Antecedent Storm: Average dry interv. days	Antecedent Storm: Median depth, percent*
Allen Creek nr Hazelwood, NC	14.4	18	10	10	10	80	3.6	26.1
WF Pigeon River above Lake Logan, NC	27.6	13	10	10	30	60	2.6	34.0
Davidson River nr Brevard, NC	40.4	47	10	30	0	70	2.9	25.7
Clear Creek nr Hendersonville, NC	42.2	10	10	0	10	90	3.1	43.3
Scott Creek above Sylva, NC	50.7	26	9	11	22	67	2.7	26.5
South Toe River at Newdale, NC	60.8	18	9	11	11	78	4.4	21.9
Cane Creek at Fletcher, NC	63.1	16	10	20	0	80	2.8	37.3
Jonathan Creek nr Cove Creek, NC	65.3	37	10	10	20	70	3.3	15.7
Mills River nr Mills River, NC	66.7	33	10	10	20	70	3.1	30.5
French Broad River at Rosman, NC	67.9	29	10	10	10	80	3.2	29.0
Hominy Creek at Candler, NC	79.8	25	10	30	0	70	2.7	27.6
Watauga River nr Sugar Grove, NC	90.8	28	10	20	10	70	2.9	43.9
North Toe River at Altapass, NC	104	24	9	0	0	100	3.0	40.2
Mud Creek at Naples, NC	109	17	10	10	0	90	3.2	45.0
Big Laurel Creek nr Stackhouse, NC	126	33	10	20	10	70	3.4	17.0
Swannanoa River at Biltmore, NC	130	33	10	20	20	60	3.5	45.3
Pigeon River at Canton, NC	133	39	10	30	10	60	2.3	39.4
Cane River nr Sioux, NC	157	33	10	10	10	80	3.5	23.7
Ivy River nr Marshall, NC	158	33	10	10	10	80	2.8	23.3
Tuckasegee River at Dillsboro, NC	347	39	10	10	30	60	2.1	19.7
Pigeon River nr Hepco, NC	350	40	10	10	20	70	3.2	8.9
French Broad River at Asheville, NC	945	72	10	10	30	60	2.6	26.6

*Percent of principal storm

Ante. = Antecedent
Interv. = Interval
W/out = Without

Table 29.—Summary of antecedent storm analysis

Floods analyzed	Total units studies: Watersheds	Total units studies: Floods	Percentage of floods with antecedent rain	Antecedent storm: Average dry interval, days	Antecedent storm: Median depth percent*
			Western Watersheds		
All	25	242	77	2.8	24.4
Summer	13	25	72	3.3	15.8
Winter	25	217	78	2.7	22.6
Largest flood	25	25	84	3.0	25.0
Largest two floods	25	50	84	3.0	28.5
With 7 in. or more rainfall	-	11	92	2.9	19.5
			Eastern Watersheds		
All	22	217	73	3.0	29.6
Summer	22	104	64	3.2	20.3
Winter	22	113	82	2.8	38.5
Largest flood	22	22	68	2.9	15.5
Largest two floods	22	44	73	3.3	13.9
With 7 in. or more rainfall	-	26	69	2.6	10
With 10 in. or more rainfall	-	5	100	3.3	6.6

*Percent of principal storm

This TVA study of flood-producing basin rainfall supports the inclusion of antecedent rainfall with the PMP - and TVA precipitation - level storms and also supports use of a 3-day rainless period between storms. From most of the studies reported here, the antecedent rainfall to the TVA precipitation ranges between 15 and 30 percent of the main storm. Relative to the PMP event, the TVA precipitation is a much smaller magnitude, and therefore, one would anticipate that the antecedent event to the TVA event is a greater percent of the main event than is that for the PMP event, for a similar dry interval. In order to not significantly change the probability of the combined storm event over the 3-day event, however, we have chosen an antecedent that is 15 percent of the TVA precipitation event.

7.3.6 Summary and Conclusions on Magnitude of Antecedent Storm.

Several approaches have been utilized to obtain guidance on the appropriate magnitude of a storm antecedent to the main storm. Each approach has limitations and must be carefully considered to obtain a logical conclusion. When considered in total, however, they provide a sound basis for selecting an antecedent storm to associate with the main storm in the TVA region. Following is a summary of the analysis that forms the basis for our recommendations (sect. 7.3.7.):

1. The ratio of the 9-day 100-yr to the 3-day 100-yr precipitation frequency values shows approximately 30 percent of the 3-day rain occurring in the remaining 6 days. The 10- to 3-day and 11- to 3-day 100-yr ratios show about 34 and 39 percent in the remaining 7 and 8 days, respectively. Direct application of these percents to the storm antecedent to the main storm is not justified since:

    a. Studies have shown the occurrences of the 100-yr 3-day value within the 100-yr 9-, 10-, or 11-day values were infrequent, and

    b. The 9-, 10-, and 11-day values are determined from a series of storms which did not have a 3- or 5-day dry interval between storms so that assuming all rainfall is in the first 3 days is a maximizing step.

2. Maximum 3-day rains at 250 stations in eastern Tennessee and western North Carolina with 25 yr of record were examined. In each case, the 6-day rainfall adjoining the maximum annual 3-day rain was determined. The data examined showed the decrease the percentage of the adjoining rainfall is of the maximum 3-day rain as the magnitude of the 3-day rain increases. These percentages decrease from approximately 25 percent to approximately 15 percent as the primary storm increases through the range of data available. The percentages might have been less if the 3-day dry period were a condition set in the analysis.

    A similar study was completed using the maximum 8-day rainfall surrounding or adjoining the annual maximum 3-day event. In this case also, there was a decrease in the percentage the adjacent rain is of the maximum 3-day rain as the magnitude of the 3-day rain increases. For the smaller storms the percentage is nearly 60 percent, while for storms greater than 6 in. it is only 34 percent.

In each portion of the study, the relationships were extrapolated to indicate an appropriate percentage at the magnitude of the 3-day main storm precipitation. These percentages indicated from 10 to 15 percent for the 6-day and from 25 to 30 percent for the 8-day adjacent rains, respectively.

3. Maximum 9-day rains greater than 4.5 in. at Asheville, Memphis, Birmingham and Louisville during the period 1912-61 were examined. Again, there is a definite decrease in the percent the adjacent rain is of the maximum 3-day rain as the magnitude of the maximum 3-day rain increases. This decreases from about 54 percent for rains between 3 to 4 in. to about 24 percent for rains greater than 6 in. There were 67 large (>6 in.) rainfall cases considered in this portion of the study. Maximum 10- and 11-day rains for these stations were also evaluated. For the 10-day rains the percentages decrease from 68 percent (for rains between 3 and 4 in.) to 25 percent (for rains greater than 6 in.) and for the 11-day rains from 88 to 30 percent. There were 58 and 43 cases of 10- and 11-day rains, respectively.

   Envelopment curves of 9-, 10-, and 11-day ratios based on extreme storms at Memphis, TN; Asheville, NC; Birmingham, AL, and Louisville, KY indicate decreasing values as the magnitude of the 3-day rain increases. The 9-day to 3-day ratio would be less than 120 percent and the 10- and 11-day to 3-day ratio would be between 120 and 125 percent.

4. Since the 25 to 50 yr of data available at most stations is an inadequate sample when considering storms approaching PMP magnitude and the rareness of the event that is necessary in these designs, statistical procedures were used to generate 40 samples of 100 yr of record. From each sample, all 3-day rains greater than 7 in. and the associated 6 days before or after were selected. A near enveloping trend line again shows the same decrease that the adjoining rain is of the maximum 3-day rain as the 3-day rain increases in magnitude. An enveloping line modeled after the trend line shows a percentage less than 30 percent at the magnitude of the PMP.

5. Since the station rainfall statistics are most representative of the lower end of the size spectrum under consideration, large major storms were examined. Three pairs of major storms were considered first. The data show that antecedent rainfall, as the percent of the major storm, decreases as the magnitude of major storm increases. Extrapolation beyond observed amounts to larger values indicates a lower percent for antecedent rainfall as would be expected from the meteorological constraints that the more intense the storm, the more unlikely it is that a strong inflow of moisture will develop in a short time.

6. Rainfalls antecedent to 23 tropical and 11 extratropical storms for 2,000-mi^2 areas were considered. First, rainfall adjacent to the storm at the location of the storm was examined for a 6-day adjoining rainfail period. Then the largest rainfall within 300 mi was considered for all 34 cases for a 6-day adjoining period. In each case, there is a decrease in the percentage the adjacent rain is of the maximum 3-day rain as the magnitude of the 3-day rain increases. Enveloping curves for all data for the case of the adjacent storm occurring at the location of the major storm indicate the adjacent rainfall at the magnitude of the PMP would be about 24 percent of the 3-day storm for the 3-day dry interval.

   For application to the PMP sequence, a maximizing step is to consider that the rains occurred either before or after the primary storm anywhere within a 300-mi radius of the primary storm. For the 3-day dry interval, the data indicate a ratio of less than 30 percent for the antecedent rain.

7.3.7 Recommendations

From the various approaches for guidance on the magnitude of rain prior to the PMP, this report recommends that 30 percent of the PMP be used for the antecedent storm when a 3-day dry interval is specified. When the 3-day dry interval is increased to 5 days, the bulk of data indicate some slight increase from similar ratios for the 3-day interval. This report suggests 39 percent of the PMP for a 5-day dry interval.

From the analysis of the data discussed in section 7.3.5 and the independent TVA study (Newton and Lee 1969), antecedent rainfall of 15 percent of the main storm is considered reasonable for TVA storm events separated by a 3-day dry interval.

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